

ICE OBSERVATION AT SEA

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CHAPTER IV. ICE OBSERVATION FROM SHORE

Observation of the ice cover from shore is conducted by hydrometeorological stations or ice posts. The stations and posts make observations daily during the entire ice season. A permanent base point for ice observation is chosen, from which the following data are recorded:

- (1) limit of surface visibility out to sea;
- (2) surface features of the ice;
- (3) proportion of surface covered by drift ice;
- (4) types of ice;
- (5) distribution of types and rendering of sketches thereof;
- (6) drift;
- (7) width of fast ice;
- (8) thickness of ice and snow;
- (9) hydrometeorological data.

The width of the fast ice and the ice edge, and changes in the thickness of the ice cover, are determined out on the ice itself.

Changes in thickness are checked once or twice every 10 days, and sketch renderings of ice distribution are accomplished on special order, but all the other observations are made daily at 0900 local time.

Along the northwestern sea frontiers of the USSR (the Baltic, Barents and White Seas), ice cover observations are usually performed at 1000 or 1100 while at the Arctic hydrometeorological stations (Kara, Laptev, East Siberian, and Chukotsk Seas), they are conducted at noon or 1300.

Ice observations are conducted at the same time each day, regardless of visibility. In poor visibility (fog, snowfall, wind-blown snow), causing the surface of the sea to be visible for less than half the distance to the horizon (less than $1/3$ at Arctic stations), the observations must be repeated later, upon 50 to 100% improvement over the former visibility, but not later than 0300 on the same day. In such instances, the actual time of observation, accurate to within 5 minutes, is entered in a column of the Log of Ice Observations from Shore.

The following data are recorded when observation has to be repeated:

- (1) limit of surface visibility out to sea;
- (2) surface features of the ice;
- (3) width of fast ice;
- (4) proportion of surface covered by drift ice;
- (5) types of ice;
- (6) distribution of types of ice;
- (7) drift.

Observations are also repeated if the ice cover undergoes significant change during the day, in which case the time is noted, and, if possible, the factors causing such change.

The thickness of the fast ice is measured on the first, eleventh, and twenty-first of the month, from 1 December to 1 May,

in areas of permanent fast ice, and in river mouths and bays.

Supplementary observations of ice cover are made at 0700 and at 1900 local time during the navigation season if so ordered by a superior authority.

The ice observation point must meet the following requirements:

- (1) maximum possible altitude above sea level;
- (2) maximum sweep of visibility out to sea, or to the gulf, bay, strait, etc, as the case may be;
- (3) proximity to the shore line and to the hydrometeorological station.

The observation point must not be less than 15 m above sea level. Its altitude is determined geodesically to within 0.5 m. In the absence of a level or theodolite, the elevation is determined by plumb-bob or barometric levelling with an aneroid. The average height of the observer to eye-level (usually 1.5 m) is added to the elevation of the observation point.

The point may consist either of a tower constructed for the purpose, the crow's nest of a light-house, the top of a hill, a seaside cliff, etc.

The distance of the horizon from the observation point may be calculated on the formula

$$D = 3.85 \sqrt{H}$$

H being the elevation of the point in m, plus 1.5 m (the average eye-level height of the observer).

Given the elevation H of the observation point, the horizon may be calculated by means of Table 3.

TABLE 3

VISIBLE HORIZON IN TERMS OF HEIGHT OF OBSERVATION POINT

Horizon			Horizon			Horizon		
Elevation ft	Nautical mile	km	Elevation ft	Nautical mile	km	Elevation ft	Nautical mile	km
[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]
1.0	2.1	3.9	18.0	8.8	16.3	64.0	16.6	30.7
1.25	2.3	4.3	19.0	9.1	16.8	66.0	16.9	31.3
1.5	2.6	4.8	20.0	9.3	17.2	68.0	17.1	31.7
1.75	2.8	5.2	21.0	9.5	17.6	70.0	17.4	32.2
2.0	2.9	5.4	22.0	9.8	18.2	72.0	17.7	32.8
2.25	3.1	5.7	23.0	10.0	18.5	74.0	17.9	33.1
2.5	3.3	6.1	24.0	10.2	18.9	76.0	18.1	33.5
2.75	3.4	6.3	25.0	10.4	19.3	78.0	18.4	34.1
3.0	3.6	6.7	26.0	10.6	19.6	80.0	18.6	34.4
3.25	3.8	7.0	27.0	10.8	20.0	82.0	18.8	34.8
3.5	3.9	7.2	28.0	11.0	20.4	84.0	19.1	35.4
3.75	4.0	7.4	29.0	11.2	20.7	86.0	19.3	35.7
4.0	4.1	7.6	30.0	11.4	21.1	88.0	19.5	36.1
4.25	4.3	8.0	31.0	11.6	21.5	90.0	19.7	36.5
4.5	4.4	8.2	32.0	11.8	21.8	92.0	20.0	37.0
4.75	4.5	8.3	33.0	12.0	22.2	94.0	20.2	37.4
5.0	4.7	8.7	34.0	12.1	22.4	96.0	20.4	37.8
5.5	4.9	9.1	35.0	12.3	22.8	98.0	20.6	38.2
6.0	5.1	9.4	36.0	12.5	23.1	100.0	20.8	38.5
6.5	5.3	9.8	37.0	12.7	23.5	110.0	21.8	40.4
7.0	5.5	10.2	38.0	12.8	23.7	120.0	22.8	42.2

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]
7.5	5.7	10.6	39.0	13.0	24.1	150.0	23.7	43.9
8.0	5.9	10.9	40.0	13.2	24.4	140.0	24.6	45.6
8.5	6.1	11.3	41.0	13.3	24.6	150.0	25.5	47.2
9.0	6.2	11.5	42.0	13.5	25.0	160.0	26.3	48.7
9.5	6.4	11.8	43.0	13.6	25.2	170.0	27.1	50.2
10.0	6.6	12.2	44.0	13.8	25.6	180.0	27.9	51.7
10.5	6.7	12.4	45.0	14.0	25.9	190.0	28.7	53.2
11.0	6.9	12.8	46.0	14.1	26.1	200.0	29.4	54.4
11.5	7.1	13.1	47.0	14.3	26.5	210.0	30.2	55.9
12.0	7.2	13.3	48.0	14.4	26.7	220.0	30.9	57.2
12.5	7.4	13.7	49.0	14.6	27.0	230.0	31.6	58.5
13.0	7.5	13.9	50.0	14.7	27.2	240.0	32.2	59.6
13.5	7.6	14.1	52.0	15.0	27.6	250.0	32.9	60.9
14.0	7.8	14.4	54.0	15.3	28.3	260.0	33.5	62.0
14.5	7.9	14.6	56.0	15.6	28.9	270.0	34.2	63.3
15.0	8.1	15.0	58.0	15.8	29.3	280.0	34.8	64.4
16.0	8.3	15.4	60.0	16.1	29.8	290.0	35.4	65.6
17.0	8.6	15.9	62.0	16.4	30.4	300.0	36.0	66.7

An orientation post is erected at the ice observation point to determine the direction toward various objects on the surface of the water. It consists of a wooden post 1.5 m high (Figure 6) to the top of which 8 pieces of wood or iron rods are attached, facing the 8 major points of the compass. The angle between each rod is 45° . The rod pointing north is distinguished from the others by attaching a piece of wood, a thick-headed nail, or in some other way. The North-South line of the orientation post must be determined by the true meridian.

1. The Limit of Surface Visibility Out to Sea

The limit of surface visibility out to sea is determined in the direction perpendicular to the shore line, and is measured in tenths of a km, in bad visibility, and in km, in good visibility.

The limit of surface visibility out to sea is the maximum distance to which, under given atmospheric conditions and light, the observer may distinguish the sea surface, and whether it is free of, or covered with, ice. In the absence of instruments, determination of visibility is by eye.

A rod range-finder or a Vladimirskiy angle range-finder is used to determine the limit of surface visibility.

The rod range-finder is used to determine distances out to sea in a fixed direction.

It consists of the 2 vertical wooden rods, I and II in Figure 7, each about two meters high above ground level, set five meters apart, the vertical plane passing through the two rods being in the required direction of observation. A sighting line to the horizon is indicated on the two rods, this being fixed at a time of clear visibility, which usually occurs on days when there is little difference between the air temperature and that of the surface layer of water.

Rod I (Figure 8) carries a pin, 2, marking the visible horizon; a scale of distances 3; the end of which 0, corresponding to the horizon, must be at the level of the pin; and a sliding sight slit 4; fixed to a bar 5; carrying a catch 1; which holds the sighter at the desired position. The pin 2, on rod I (Figure 7 and 8) is set at a level somewhat lower than the observer's eye. The

observer finds the horizon of the moment through the aperture (dioptric), 4, along pin 2a of rod II, while the plane through pins 2 and 2a of the 2 rods leads to the horizon visible in good weather (Figure 7). During an observation, the sight aperture (dioptric) is moved upward on rod I, until the horizon visible at the given moment through that aperture is in line with the pin on rod II. The position of the aperture along the scale of distances marked on the rod is noted. This gives the range of the visible horizon at the given moment.

The Vladimirskiy angle range-finder is erected at the observation point and is used to determine direction and distance to any desired point on the surface of the sea.

The angle range-finder consists of a metal rule (alidade), 1,750 mm in length, at the ends of which are mounted verticals with sighting devices (Figure 9). One of them, the objective, consists of a circular aperture with cross-hairs, while the other has a vertical slit 3, the edge of which carries a mm scale. A rack-and-pinion gear moves a bar 4, with a tiny round hole in its center 5, up and down the vertical, while the vernier permits readings to an accuracy of 0.1 mm. The alidade 1 is mounted to the bushing 7, in the circular mount 8, by a vertical conical axis 6, permitting it to be rotated in any direction around the circular plate 9, bearing a scale from 0 to 360° mounted to the same bushing and fastened to the base by a nut 10. The axis of rotation 6, carries a bent rod 11, the end of which bears a slot and pointer for accurate reading of the degree scale. 3 adjusting screws 12, in the base of the instrument, permit the plane of the alidade 1, to be adjusted to the horizontal, while 3 other screws 13, serve to fasten the base of the instrument to a special metal plate 14, mounted in its foundation. Where the post is of masonry, the plate

is fastened by means of bolts cemented in. Where it is of wood, wood screws are used. The instrument is normally covered with an iron, wooden, or canvas hood.

To determine direction and distance to a given point on the surface of the sea, the instrument must be set on the true meridian so that zero on the horizontal circle faces northward. Rotating the rule until the objective points at A, the most characteristic cake on the edge of the drift ice (Figure 10a), and then sighting through the hole in the eyepiece, the rack-and-pinion gear are rotated until this point corresponds to the junction of the cross-hairs in the objective. After this has been done, 2 readings are taken, one along the vertical scale, to an accuracy of 0.1 mm, and one along the horizontal scale from the pointer (to an accuracy of 1°). Then without changing the position of the rule, and sighting through the eye-piece, the rack gear is turned until a point is reached at which the visible horizon of the sea is fixed in the cross-hairs (Figure 10b), and the vertical scale is read again.

The distance to the point on the surface of the sea is usually calculated on P. V. Melent'yev's nomogram, which carries 3 scales. The uppermost scale shows the elevation of the instrument above sea level in m. Along the lower scale one plots the difference in readings, in mm, between the sightings on the object and on the horizon. When a rule is placed across the corresponding points on the upper and lower scales, the point at which the rule intersects the curved scale in the middle of the chart gives the distance to the object, in km. The direction of the object is read off along the horizontal circle, calculating from the north to the east, from 0 to 360°.

If the line of the visible horizon (in the direction for which information is being sought) is blocked by the shores of a gulf or bay, island, etc, the cross-hairs are centered on the shore line in taking reading a. Aiming the objective at the point being observed gives reading b.

The distance measured from the instrument to the shore line is plotted on the middle scale of the nomogram and the height of the observation point on the upper scale. A straightedge set along these two points on the middle and upper scales gives, at the intersection with the lower scale, reading c, providing the true position of this shore line relative to the horizon.

The true position of the point observed relative to the horizon is calculated on the formula

$$x = b - a + c$$

The straightedge is now used to connect the point on the upper scale, corresponding to the height of the observation point, and that on the lower scale, corresponding to x. The distance to the point under observation is then found on the middle scale.

The foregoing observation is not performed under poor conditions of visibility (fog, haze).

2. Observations of the Appearance of the Ice

By origin, ice is divided into fresh water, sea, and continental (glacial). Fresh-water ice is formed in rivers and lakes and is carried out to sea in the spring and fall. Sea ice is formed locally, in the sea, from salt water. Continental ice takes the form of glaciers flowing from islands and the mainland coast. They are encountered in the sea in the form of fragments broken away from the glaciers.

All these forms of ice differ widely in physical, chemical, and other properties. All 3 types are rarely found simultaneously in the oceans and seas or portions thereof, although this does occur along the northwest shore of the Atlantic, near Novaya Zemlya, and at some other points. There are areas in which 2 of the types are found together with fair regularity. Sea and fresh water ice are found near the mouths of large rivers and in areas of flow of currents related to river outflow. Sea and continental ice are also found together. Large quantities of the latter are seen in the vicinity of large glaciers, although they may also be found thousands of km from their points of origin.

Continental ice is readily distinguished by its shape, vertical dimensions, color, and sometimes by clearly-differentiated stratification resulting from annual cycles of thaw and accumulation.

Sea ice is distinguished by its salinity (declining with the passage of time). It is cleaner and brighter than fresh-water ice, and may also be identified by its color shadings, surface structure, etc.

Sea ice is divided into 2 major sub-types: fast and drifting.

Fast ice includes both solid masses firmly attached to the shore (the ice foot in the various stages of its development) and other ice formations resting on shoals, including drift ice temporarily stranded. The classification of the latter with fast ice is based primarily on considerations of navigation.

In some seas or portions thereof, fast ice may predominate in winter, while being negligible in quantity during the summer. Fast ice may be identified by the absence of tidal leads or signs of motion, evidence of vertical fluctuation, tide cracks, pressure

ridges at the seaward edge of the ice foot, etc. It is to be remembered that fast ice may include ice originating elsewhere.

Drift ice comes in a wide variety of shapes, sizes and age, and is in constant motion under the influence of wind, currents, and waves.

Fast ice is classified by type. Note is taken not only of type but size: width and length of fast ice, its thickness, and other indices similar to those noted for drift ice.

Certain transitional stages are hard to identify, despite the fact that precise terms exist with which to describe them (i.e., the transition from first-stage fast ice ("ice-crusts shore") to young fast ice. The criteria depend upon circumstances.

Determination of the amount of fast ice and open water is arrived at visually, on a ten-point scale. When there is more than half a point of fast ice, it is rated as one point, while less than half a point is zero-with-asterisk (0*).

Fast ice exceeding 9.5 points but not equal to 10 points (there being small areas of open water, or polynias with floating ice) is given as 10 in a square (10). A tendency has recently appeared to supplement this data with information on the width of the fast ice, permitting a more precise concept of the state of the ice in the area under observation.

If fast ice and drift ice are both found within the range of vision, it is desirable to determine both the width of the ice foot and the amount of fast ice, as for purposes of navigation procedures it is desirable to provide data on the total "Iciness" of an area, and the ratio between fast and drifting ice.

Full use of observations along the course of vessels, and from the air, should also be made in characterizing fast ice.

3. Determination of the Proportion of the Surface Covered by Drift Ice

Determination of the proportion of the surface covered by drift ice is made by eye from the observation point on the basis of the entire sea surface clearly visible, employing the ten-point scale. The criterion is the relationship between total area covered by ice cakes and the clear water between them. The maximum ice coverage (consolidation), when no water is visible at all is 10 points. Absence of ice is represented by 0 points. The gradations between these represent various ratios between ice-covered to water surface. These ratios, their representation by points on the scale, and in description, is adduced in the ice coverage (consolidation) scale, shown in Table 4.

TABLE

ICE COVERAGE (CONSOLIDATION) SCALE

Points	Ice cake-to water ratio	% ice coverage of water surface area	Description of ice coverage
0	No ice	0	Open water
1	1/9	10	Very open ice (scattered ice)
2	2/8	20	
3	3/7	30	
4	4/6	40	Open ice (broken ice)
5	5/5	50	
6	6/4	60	
7	7/3	70	Close ice
8	8/2	80	
9	9/1	90	
10	No areas of water	100	Consolidated ice as far as the eye can see

Both the table, and the concept of evaluation of ice coverage, are the work of GOIN [the National Institute of Oceanography]. An interdepartmental commission has added the column, "% ice coverage of water surface area."

TABLE 5
SCALE OF CONSOLIDATION

[[Note]: Taken from Manual for Observations of the Ice on Arctic Seas, Rivers and Lakes, by Arctic Hydrometeorological Stations, No 31, Northern Sea Route Press, Moscow and Leningrad, 1953).

Ratio of area covered by ice of uniform degree of consolidation to total area over which this		
Balls	Description	ice is found, %
0	Open water with isolated cakes	0
1	Occasional cakes	10
2	Extremely open ice (scattered ice)	20
3	Very open ice	30
4	Open ice	40
5	Medium close ice	50
6	Slightly open ice	60
7	Close ice	70
8	Very close ice	80
9	All-but-consolidated ice	90
10	Consolidated ice	100

The scale of consolidation used at polar stations (that of the Arctic Research Institute) is also based on comparison of the area of drifting ice with that of the intervening water surface, but is defined with greater detail, in terminology (Table 5).

If the ice is unevenly distributed over the surface of the sea visible from the ice point, the orientation post or a compass is used to divide the entire visible area into a series of sectors, based on the 8 major directions. These sectors are designated by the following numerical indices, adhered to by all hydrometeorological stations:

Sector	N-NE	NE-E	E-SE	SE-S	S-SW	W-SW	W-NW	N-NW
Index number	I	II	III	IV	V	VI	VII	VIII

When ice coverage (consolidation) varies in various points of each sector of the chart, 3 to 5 point numbers may be entered in each sector, the arithmetic mean of which represents the average consolidation of the ice in the given sector, and is entered alongside the index number for the sector, as shown in Figure 12. The maximum and minimum ice coverage (consolidation) point numbers in the entire area of visibility are entered in the corresponding column of the observation chart, in addition to the average consolidation number for the total area (the sum of all the local point numbers in the various sectors, divided by the number of numbers, and rounded off to a whole number). The point number most characteristic of the entire visible area indicates the dominant degree of consolidation of the ice.

When the consolidation of the ice in various directions is not uniform, V. L. Tsurikov recommends a careful division of the visible area into 2 portions, one containing the ice of greatest, and the other, of least, consolidation, with an evaluation of the consolidation in each half.

To facilitate evaluation of consolidation, the National Institute of Oceanography, in collaboration with the Naval Observatory

at Arkhangel'sk, have adopted the graphic scale (Figure 13) proposed by Ya. Ya. Gakkel'.

Gakkel' recommends that consolidation be evaluated separately for young and older ice forms, a method that completely justified itself in observations in the White Sea in 1949.

4. Identification of Types of Ice

Identification of types of ice is done separately for fast and drift ice seen from the observation point over the entire visible area.

In determining types of fast ice (first-stage fast ice, fast ice, ice foot, stranded hummocks, etc), the most characteristic type seen over a considerable area is entered into the shore-observation ice-cover log. Other types are noted when they are clearly identifiable and occupy considerable areas of the visible space.

In determining the percentage ratio of types of drift ice, which may, for practical purposes, be divided into 2 major groups, ice fields and cake ice, those types are recorded which are present in considerable quantity, taking 100% as the total area of cakes of that type of drift ice alone. The accuracy of the percentage given is adequate if it is within 10%.

Of much significance in observations of type is the shape of the cake, as the angularity or curvature of outline are good indications of ice dynamics and of time when break-up occurred.

The degree of hummockiness and of destruction of the ice is also determined at the same time.

Hummockiness

Observations of the structure of ice cover must describe the state of the surface, rafting, and hummocking of the ice. Hummocking is of particular importance, as it assists in determining age and average strength (thickness), factors essential to compilation of the ice balance.

Hummocking is measured by the ratio of area covered by hummocks to the total ice area. It is measured in points on a 5-point scale, corresponding to the percentage of ice represented by hummocks (Table 6).

TABLE 6

HUMMOCK SCALE

([Note]: This scale is from the Manual for Observations of the Ice on Arctic Seas, Rivers and Lakes, by Arctic Hydro-meteorological Stations, No 31, Northern Sea Route Press, Moscow and Leningrad, 1953).

Points	% of visible area covered by hummocks	Av % of ice surface covered by hummocks	Description of ice surface
0	0	0	Level ice
1	0-20	under 10	Level ice with occasional hummocks
2	20-40	about 30	Mildly hummocky ice
3	40-60	about 50	Hummocky ice
4	60-80	about 70	Very hummocky ice
5	80-100	about 90	Solidly hummocky ice

Hummocks are usually found on ice fields, floes, large and small cakes, and fast ice. Hummocks are divided into those caused by heaping and those caused by marginal crushing. Hummocks

due to heaping are characteristic of year-old and winter ice, and result from the piling of large cakes on each other. When the cakes rise on contact they break and sometime take on a vertical position. Marginal crushing is usually a characteristic of 2-year-old and polar ice. This results from collisions of cakes of considerable thickness, with further heaping-up of ridges consisting of small fragments along the edges of the cakes.

In characterizing the hummocking of ice by means of the scale, note is also taken of the nature of the hummocks, i.e., whether the hummocks are distributed over the surface in orderly or disorderly fashion, while the height is also measured. Where small cakes or ridges or barriers are concerned, hummockiness is not measured on the scale. In such situations, note is taken of the height of the ridge or barrier, its direction on the compass, and the distance between ridges or barriers.

The height of hummocks above the surface of the ice cover must be determined out on the ice. If this is impossible, the hummock height, h , is determined from the shore on the Ivanov perspectometer scale of elevations, based on the distance to the hummock, d , by the formula $h = d \operatorname{tg} \alpha$.

The dominant and the maximum height of the hummocks are usually taken into consideration. In determining the dominant height, a number of hummocks are selected, which are most typical for the given area, and the average measurement is the one recorded. In some cases it is desirable to recommend aerial photography. These photographs make it possible to calculate both the area of the hummocked ice and the height of the hummocks (the shadows in stereoscopic slides being the basis for the latter determination).

It is also of value to estimate the age of hummocks (young,

old, polar). A number of indirect signs are used for this purpose: the thickness and color of the ice at cracks, the weathering and thawing of the cakes and hummocks as a whole, the snow cover and the weathering of shapes, the latter being characteristic of old, polar hummocks.

Disintegration of Ice

External signs of thaw and weathering of ice are of high practical importance. These signs appear in a specific order, each replacing the next. In 1943, the Arctic Research Institute developed an experimental scale of disintegration based on complex evaluation of symptoms of various stages in thaw. This scale has since been improved as a result of the experiences of observers working on the Arctic seas, and it has been further modified in the Hydrometeorological Service.

The disintegration of the ice as defined in the scale (Table 7) is evaluated by eye in terms of signs of thaw or mechanical destruction. In many places thaw and destruction of sea ice begin near the shore, where this is facilitated by the higher water and air temperatures, the flow of water from the mainland, and the relatively high contamination of water and ice near the shore.

TABLE 7

ICE DISINTEGRATION SCALE

([Note]: Virtually the same scale is used in the Hydrometeorological Service. The Manual for Observations of the Ice on Arctic Seas, Rivers and Lakes by Arctic Hydrometeorological Stations, issued by the Northern Sea Route Press, Moscow and Leningrad, 1953, presents a five-point scale with more detailed definitions.)

Points	Definition of Ice Disintegration
[1]	[2]

[1]

[2]

- 0 Complete lack of external signs of disintegration. No polynias or puddles. Ice fracture lines are sharp. The surface of the ice is white.
- 1 A few puddles. Cracks. No polynias.
- 2 Many puddles. Some polynias. The edges of the cakes are rounded, and often form cornices overhanging the water. The surface of the ice is chiefly white.
- 3 Many polynias or puddles, connected by streams. Most of the ice has a lace-like surface, but the peninsulas between thaw polynias are still white or dirty brown. There are submerged rams in the broken ice. Mushroom-shaped cakes are common. The smallest cakes are very water-logged, and gray in color.
- 4 The ice is in an advanced state of disintegration due to thaw, and low in the water. Only elevated parts of cakes, very water-logged, and gray in color, project above the water. As in 3-point disintegration, the ice sometimes remains in the form of fairly large fields, but these are so interwoven with thaw polynias as to resemble lace.

In addition to an estimate of degree of disintegration, the observation log should also carry sketches of the various types of disintegration cornice, mushroom, or ram cakes etc.

Observations of ice disintegration are conducted in all seas until the onset of the period of stable autumnal ice formation. After air temperature has steadily become negative, ice disintegration reporting ceases, to be renewed with the beginning of the spring thaw. If the observation point is very high or far from shore, check observations of ice forms, hummockiness and disintegration are made from the fast ice or its foot.

5. Observations of the Distribution of the Ice and Sketch Rendering

Observations of the distribution of the ice, and sketch rendering, is made by the naked eye, or through binoculars. The results of examination of the entire visible surface of the sea are entered in the corresponding section of the Log of Shore Observations of Ice Cover. Observations are made daily, but if the situation does not change over a period of days, it is not necessary to provide a complete description of the ice distribution and the state of the ice cover on each occasion. During such periods it is sufficient merely to note minor changes. At times when the picture is changing, detailed descriptions are compiled daily. In making such observations, it is necessary to take note of the most important and governing elements in the ice classification and the state of the cover.

First one notes the portions of the sea covered by fast and drifting ice, respectively, and the course of the boundaries of each, particularly insofar as the drifting ice is concerned; the presence of polynias and channels in the fast and drifting ice, with information as to their size and position; and any data on floebergs, icebergs and stamukhi with number, dimensions, state and location. In addition, note is taken of disintegration or hummocking of the fixed cover, consolidation or break-up of the drift ice and the appearance of ice blink or water sky, and the direction in which they are observed. In addition, record is made of everything that may describe, directly or indirectly, the thickness, strength and penetrability of the ice cover, such as the closing and opening of summer and winter navigation, snow cover on the fast ice, the nature of hummock distribution, and heights; thickness of the drift ice, detailed description of the passage of vessels

through ice, ice crossings, and the beginning and end of any type of transportation over the ice; aircraft runways on the ice, and the dates they go into and are taken out of service; the initial and terminal dates of fishing through the ice, and dates on which hunters have gone out on the drift ice for sea mammals, etc.

Reports of ice cover in Arctic seas must also specify the degree of contamination of the ice, judging by external indications. A special scale (Table 8) is used for this purpose. Observations of the contamination and color of the ice provide supplementary characterization of the ice cover, which sometimes helps to provide a more precise picture of ice dynamics. Thus, discovery in the open sea of a dirty cake surrounded by clean fields, may help to resolve the problem of point of origin and direction of drift. High "contamination" of the ice is also a good sign of the intensity of thaw.

At one time observers limited themselves solely to noting the presence of this type of ice. At present, however, it is recommended that note also be made of the degree of contamination, color shadings and, if possible, the nature of the contaminants (organic, mineral, etc). Therefore, this aspect of the observations also includes studies of various casual objects on the ice (drift-wood, boards, piles of stone, buoys), which may serve as benchmarks helping to determine drift. Sometimes artificial coloring of cakes is employed to permit subsequent judgment as to their motion.

TABLE 8
CONTAMINATION SCALE

([Note] From Manual for Observations of the Ice on Arctic Seas, Rivers and Lakes by Arctic Hydrometeorological Stations, No 31, Northern Sea Route Press, Moscow-Leningrad, 1953)

Contamination of ice, as percentage of total visible area of ice	
Balls	
0	Clean ice with trace of dirt
1	Slight contamination (10-40)
2	Medium contamination (40-70)
3	Dirty ice (70-100)

In performing these observations one must also note the color of the contaminants (dirt) from the vantage point of the ice and, if possible, its origin (mineral, organic particles).

The distribution of the types of ice is sketched from the observat on point every 5 days: on the fifth, tenth, fifteenth, twentieth and twenty-fifth, and the last day of each month. This is done on special forms, and to scales of 1:25,000, 1:50,000, 1:100,000, 1:150,000, and 1:200,000.

At Arctic hydrometeorological stations an ice chart must be sketched in daily, but if there is no visible change in ice conditions, this may be omitted. Once fast ice has reached the horizon, a sketch is made only once in ten days, this being timed with ice-thickness recording.

Sketches of this type are drawn on outline charts of the particular body of water whose ice regime is under investigation. The charts show its shape and boundaries. With the ice observation

point as center, concentric arcs or circles are drawn at 3 to 5 km intervals, the radius of the outermost corresponding to the distance to the horizon visible from the given point. Radii are also drawn along the 8 major points of the compass.

When filled in, the chart carries the name of the body of water and of the hydrometeorological station, the date and time the sketch was made, its scale, and the symbols used to describe ice conditions. Before the sketch is drawn, the form is mounted to a special map-board (Figure 14). To sketch in the ice forms on the chart, the distance to them is measured by the angle range-finder or by eye and the direction is determined by orientation post or angle range-finder. The Ivanov perspectometer may also be used in determining the location of the edges of fast ice, stranded hummocks, orientation cakes, polynias, etc.

The edges of drift and fast ice, and the contours of each area of open water, with iso-lines for the borders of drift ice of uniform compactness, are entered on the chart in corresponding scale. The various ice forms are depicted by conventional symbols, their frequency of occurrence in approximate ratio to ice coverage (consolidation) being indicated in points, the number being circled and entered in the middle of the given area. Other symbols are used to identify hummocks, ropaks, leads, polynias, cracks, thaw polynias, cracks due to currents, offshore water, water sky, ice blink, and channels cut by ships in fast ice. The charts must also show roads on the ice, landing strips, and cross-sectional thickness of the ice if measured within 2 to 3 days. If less than $\frac{2}{3}$ of the water surface of the object is visible, observations are shifted to a later hour or the next day. Each blank chart so filled out is signed by the individual who has made the particular observation.

The following is the order of procedure in sketching the ice from the observation post: the clean form is fastened to the board and oriented to the north (Figure 15a), whereupon the shore line is drawn in, then the radial lines, and the boundary of the visible surface of the sea at the moment of observation (Figure 15b).

Next the fast ice edge is located and entered (Figure 15c). This is to permit subsequent analysis of the growth of the fast ice, the edge of which will be recorded at various stages of development (Figure 15d).

Thereafter the degree of hummocking and of disintegration of the fast ice is recorded (in points), and the typical hummock forms are sketched in, along with stamukhi and stranded icebergs (Figure 15e).

Next the edges (boundaries) of open water and drift ice are sketched in (Figure 15f), the consolidation (coverage) of the latter (Figure 15g), and indication as to the type of drift ice (Figure 15h).

6. Observation as to the Drift of the Ice

Observation as to the drift of the ice made from the ice observation point is done by eye, or with the Ivanov perspectometer, the angular range-finder, or the theodolite (sometimes 2 theodolites are used). This work consists of determining the direction and speed of ice drift.

In observations by eye, the direction of drift is determined with the aid of the orientation post or the compass. The log should show the direction in which the ice is going, i.e., that

of the 8 major points on the compass toward which the ice is drifting.

The rate of motion as determined from the shore is recorded by means of the attached scale (Table 9), which is recommended by the Hydrometeorological Service and the Northern Sea Route Administration.

It is also desirable to use 2 range posts in a line perpendicular to the shore. The observation is made at the moment when the most characteristic cakes come in line with the posts. This increases the accuracy of evaluation by eye.

More accurate data on ice drift may be obtained by using the Ivanov perspectometer or the angle range-finder. Sighting the angle range-finder on a cake previously selected, moving one to 3 km offshore, its location is determined to within 0.1° by counting off on the horizontal circle, and to 0.1 mm on the vertical scale of the eye-piece. These are entered, along with the time of observation. Leaving the alidade of the angle range-finder in its previous position, the sight-line is aimed at the visible horizon, and a reading is again taken on the scale. After 6 minutes have passed, during which time the sighting line is moved along with the cake under study, a reading is again taken along the horizontal circle and the vertical eye-piece bar, whereupon the range-finder is sighted on the visible horizon of the sea. The two directions thus found for the cake are entered on the form, the line of drift forming an angle to the right of the meridian. The direction is recorded to an accuracy of 10° . The distance between the 2 points at which the cake was seen is read off the chart and converted to km. The rate of drift, in km per hour, is now entered to an accuracy of 0.1 km. In determining the drift

of ice by means of the angle range-finder, it is necessary to take into account the maximum distance from the cake which depends upon the elevation of the instrument above sea level (Table 10).

TABLE 9
SCALE OF ICE DRIFT SPEED

Points	Verbal description of rate of motion	Rate of motion, km/hr
0	No motion	0
1	Motion barely discernable	0-0.5
2	Definite motion	0.5-1
3	Rapid motion	1-3
4	Very rapid motion	More than 3

TABLE 10
MAXIMUM DISTANCE TO CAKE OBSERVABLE BY ANGLE RANGE-FINDER, DEPENDING UPON HEIGHT OF POINT

Height of instrument above sea level, m	Maximum distance to cake km	Height of instrument above sea level, m	Maximum distance to cake, km
10	0.8	40	3.0
15	1.1	45	3.4
20	1.5	50	3.8
25	1.9	60	4.6
30	2.2	70	5.4
35	2.6		

To observe ice drift by the theodolite alone, the instrument must be mounted at the observation point so that the nearest point

at the surface of the sea will be viewed from an angle of not less than 45° , i.e., cakes will be visible from a distance equal to the height of the observation point. To determine the distance to the cake under observation, a reading of the vertical angle CAB (Figure 16) is taken, the tangent to which is multiplied by the height of point AB. The readings on the theodolite panel, and data of wind and ice conditions are entered in the appropriate log book.

When a series of such observations is made, note is taken of the time, the point at which the cake is located at various moments of observation along the directions obtained, and the distances entered on the radial graph used to work out piloting observations (Figure 17) or on the vector circles of Molchanov, Druzhinin and others. By connecting the extreme points via a straight line, we obtain the mean direction of drift, which is taken off the chart by a protractor.

The rate of drift is calculated by measuring the distance between the first and last points on the drift of the cake under observation, and by dividing the magnitude thus obtained by the duration of observation, in hours.

To avoid errors in distance the theodolite is always sighted at the same point on the cake.

If the point is high enough a single theodolite suffices to determine drift for 20 to 25 km, to satisfactory accuracy (10%).

To speed the calculations it is desirable to compile a table with values for distances and speeds at the given point calculated for vertical and horizontal angles.

Observations over ice drift by 2 theodolites requires that a base line more than a km in length be laid out. The major base line is laid out on a smooth spot, if possible, and is measured not less than 3 times with a steel measuring tape. The permissible maximum error must not exceed 0.001. Observations of the drift of a chosen target cake by 2 observers are taken every hour, at moments agreed on in advance, the horizontal verniers being read (at ten-minute intervals). Excessively acute or obtuse angles must be avoided in taking bearings on cakes by theodolite. Angles of less than 30° and more than 150° must not be used under any circumstances.

All observations on ice drift must be accompanied by determination of the speed and direction of the wind, the consolidation of the ice in points, its appearance, cake sizes, and degree of hummocking. All these data are entered in the log. Cake sizes and hummockiness are entered as remarks.

In ice drift observations, the sea in which this is being done must be taken into consideration. In seas without tides a single observation suffices, but in seas with tides, depending upon the type of tide, the observations are run continuously for 13 or 25 hours, so as to cover a complete half-day or full-day tidal cycle.

Elaboration of the observations is performed on mm-ruled graph paper, on which the shoreline and the 2 points have been drawn to a specific scale. Circles of any desired radius are drawn from the 2 points of observation. The circles are divided by degrees (the northern portion of the meridian being 0°), and represent the visible portion of the horizon (Table 18). These circles replace the protractor, and thereby greatly speed the

lapping of the points thus obtained. The true azimuths of the cake thus observed constituting corrected readings on the horizontal vernier, are applied for each point. The point at which these azimuths intersect is the location of the cake at any given moment. The points obtained are successively connected by lines, and these reveal the course followed by the cake.

The line connecting the initial and terminal points of the drift shows the mean direction of drift of the cake, and its length, divided by the time represents the average rate of drift.

The final data are entered in a log, following the form shown in Table 11.

TABLE 11

		<u>Drift</u>		<u>Wind</u>		<u>Nature of ice</u>			
<u>Time</u>		average		speed,		consoli-			
Date	Series	Hrs	Min	direction	speed	direction	m/sec	type	dation Remarks

In the "Time" column, the time, to the minute of the start and finish of each series of observation is entered. The data entered in the remaining graphs apply to the entire series of observations.

R. N. Ivanov Perspectometer (VB-49)

This instrument designed to measure wave components is also used for a number of other types of observations including ice studies (Figure 19).

The instrument permits determination of drift, surveying of the edge of fast or drift ice, measuring the height of hummocks and stamukhi, and determination of the size of cakes and leads.

The perspectometer is incapable of replacing the rod range-finder, as its application is limited by its grid to a radius of 2 to 5 km.

In seas with tides, in which the tide is not smaller than 0.5 m, all observed magnitudes are corrected by a factor, K, which depends upon the phase of the tide at the moment of observation. This correction is obtained by subtracting the sea level at the moment of the reading from the elevation of the optical axis of the instrument over zero on the tide gage. The sea level is determined by dip rod or by reading from the mareograph tape.

The Ivanov instrument consists of a monocular (1/2 of a 6 X 30 prism binocular), fixed in permanent position to a stand carrying a prism. The stand rests on a knife-edge and is fastened by screws to a mount, which is rigidly attached to a disc rotating, with stand and tube, over a dial. The dial also is capable of rotating through 360° around its vertical axis, and is fixed at any given point by a stop screw. A micrometer gage enables the tube to be sighted very accurately on the desired glacon. The dial is connected to a support with 3 lift screws resting on a platform fastened to the foundation of the instrument. A level in the disc is used for levelling the instrument in place.

A perspective grid (Figure 20) is mounted in the monocular. The grid has a distance scale, 1, which is used to measure the distance to a point on the ice, in km. One graduation on the distance scale in the portion from 0.1 to 0.3 corresponds to 10 m on the surface of the sea while it is 50 m between 0.3 to 0.5, 100 m between 0.5 and 1.0 and 500 m between 1.0 and 2.0.

The vertical scale, 2, to the right of the distance scale

permits determination of the height of ice formations, such as hummocks, stamukhi, icebergs, etc.

Each graduation on this scale represents 0.5 m, as indicated toward the top of the grid.

The lines numbered 3 on the grid which join horizontal line 4, representing the surface of the sea, correspond to parallel lines 5 meters from each other. These lines are used to determine the rate of motion (drift) of ice moving perpendicular to the beam of vision.

In setting up the VB-49 perspectometer at an ice observation point, note must be taken of the data at the top of the perspective grid. Thus, if $H = 10$ m, the instrument is set up 10 m above sea level, in which case the horizontal line 4 of the grid is focussed on the image of the visible horizon at sea, and the 0° mark on the dial must face North. Next, the stop screw fixes the dial in place. In addition each perspective grid carries a constant, HF , representing the product of the height of the instrument foundation and the focal length of the viewing tube.

(a) Ice drift determination with the VB-49 may be by 3 methods, depending upon the direction and rate of motion of the floes.

The first method is used when ice is drifting rapidly along the shore, the second when ice is moving slowly in the same direction, and the third, when ice is drifting toward the shore (in the area of the ice observation point) or away from it. In the first case, the distance is determined along the range scale, and the direction to the best target cake along the graduated dial. These data and the time, are entered in columns 2, 4, and 5 of a special log (Table 12). When six minutes have passed the observations

are repeated and again entered in the journal. Should the direction toward the cake change by 30° or more during the 6 minute period, that is the end of the observation. Should the position have changed by less than 30° , a third observation is made 12 minutes after the initial reading, and so on, until the total change in the position of the cake has changed by 30° .

All the angles of direction and measured true distances to the cake are entered on a special blank, where the position of the perspectometer is also noted. The points thus entered are connected by a broken line which describes the actual drift of the cake (Figure 21).

By connecting with a straight line the extreme points of the course followed by the drifting cake, we find the general direction of drift (GDD) of the cake for the period of the observations.

The general speed of drift (GSD), in m per second for the entire period of the observations is calculated on the formula

$$GSD = \frac{L}{t \cdot 60}$$

in which L is the distance between the extreme positions of the cake in m, taken off the plot, and t is the period of observation, in minutes.

All the results of elaboration of ice drift observations are entered in columns 12 to 15 of the log as shown in Table 12.

When drift is insignificant, i.e., when the angle between the points recorded at 6 minute intervals is less than 5° , recourse is had to the second method of determining drift. In this situation the perspectometer is mounted so that the best target cake drifts along one of the horizontal lines of the perspectometer grid, a stop-watch being started when the target passes one of the

2 outside sloping lines of the grid (10 m). When the target passes the other outside sloping line, the stop-watch is shut off.

The results of the stop-watch and perspectometer dial readings are entered in columns 2, 4, 6, and 13 of the log (Table 12). If the target cake drifts from left to right, 90° is added to the dial reading. Vice versa if the drift is from right to left, 90° is subtracted.

The speed of drift is calculated on the formula

$$v = \frac{20K}{t}$$

in which v is the rate of drift in m per second, 20 is the distance in m between the 2 sloping lines on the grid, K is the coefficient of correction, and t is the period of observation in seconds.

The data on the direction and rate of drift are entered in columns 14 and 15 of the log.

When the third method of ice drift determination is used, the perspectometer is mounted so that the sighting axis follows the direction of drift. Then the best target cake is brought into line with one of the graduations on the distance scale. At the moment that this occurs a stop-watch is set in motion. It is turned off after a brief period (100 to 150 seconds), when the cake having traversed several graduations on the scale, is directly in line with one of them. The readings of the dial, the stop-watch, and the difference in readings along the distance scale representing the space traversed by the cake during the period of observations, are entered in columns 4, 5, and 13 of the log (Table 12). If the cake drifts toward the ice-observation point 180° is added to the dial reading while if the drift is away from that point, the same number of degrees is subtracted.

The rate of drift, v , is calculated on the formula

$$v = \frac{LK}{t}$$

in which L is the distance traversed by the cake in m, t is the duration of the drift in seconds, and K is the factor of correction.

The data thus obtained on the direction and rate of drift are entered in columns 14 and 15 of the log. To convert the rate of drift (given in m per second) into km per hour, one multiplies by 3.6.

(b) The edge of fast or drift ice is surveyed along the distance scale of the perspectometer, along which distances are measured to typical points along the edge, A, B, C, D, E, F, G, H, not more than 2 km from the instrument (Figure 22). The angles toward these points are read off on the dial to an accuracy of 1° . The distances and angles thus found are entered in columns 4 and 5 of the log (Table 12). The true distance to each point on the edge is calculated by multiplying the data obtained by the variable factor K (column 9). The product is entered in column 10.

The directions and true distances are entered, in accordance with the appropriate chart scale, on special forms where the point at which the perspectometer has been mounted is first indicated. The ice edge line is found by connecting the series of points on this form.

(c) The height of hummocks and stamulchi is measured on the elevation scale of the perspectometer, to the right of the distance scale. The measurement consists of determining the number of graduations on the scale between which lie the entire height of the hummock or stamulchi from foundation to base. This number of graduations is multiplied by the value of each graduation

on the scale of elevations, and by the variable factor K. For precise measurements it is recommended that the height of the highest hummock, and also of 10 hummocks of standard height be measured, the mean being taken. All the observations are entered in columns 7 and 11 of the log (Table 12).

(d) Determination of the horizontal dimensions of the cakes and leads by means of the perspectometer is done along the distance scale. In doing so, the distance to the forward and the rear edges of the cakes or lead are noted, whereupon the readings are multiplied by the variable K. The difference in the true distances expresses the length of the floe or lead in km. The data are entered in columns 5 and 10 of the log (Table 12).

7. Determination of the Width of the Fast Ice

Determination of the width of the fast ice is performed not less than once in 10 days after completion of observations of the state and motion of the ice. The width is always measured in the same direction and toward the most open portion of the sea, usually perpendicular to the shore. With this object, a range rod is erected at a point close to the ice observation point. Markers are frozen into the fast ice some distance apart for use with this rod. The distance between the markers depends upon the width of the fast ice. If it is wide, they are set up 0.5 or 1 km apart, but if narrow they are spaced 100 m apart.

The width of the fast ice from the shore to the edge may also be paced off or taped off from the range rods on the shore.

The width of the fast ice must be determined to within 10% of its maximum possible magnitude. Thus, if it is 5 to 10 m wide, the accuracy must be to within one m, while it is from 5 to 10 km it must be to within one km, etc.

If the width of the fast ice cannot be measured directly from the ice itself this is done from the shore by eye or with the aid of the Ivanov perspectometer or the angular distance gauge.

If the width of the fast ice undergoes very little change, there is no need to repeat the measurement. All that is needed is to mount a high marker at the edge. Then it is easy to determine changes in width without going out on the ice.

If for some reason it is entirely impossible to measure the width of the fast ice but the point to which it extends is known, its width in km is entered in the appropriate column of the graph by taking a map reading.

If visibility is limited, or if the edge of fast ice is beyond the horizon, the visible sea surface, in km, is entered in the column for fast ice width and ahead of it the symbol $>$.

[See page 37 for Table 12]

If no determination of the width of the fast ice has been made, this column is crossed out, and the reason for the failure to conduct an observation is stated in the remarks.

In addition to determining the width of the fast ice in the usual direction, the entire visible fast ice is examined each day by eye.

6. Observation of the Thickness of Ice and Snow

Observation of the thickness of ice and snow consists of:

(a) systematic measurement of the full thickness of the ice.

In certain cases, this is supplemented by measurement of the thickness of various layers of ice: the clean, transparent, bluish or greenish layer, the ice without significant contaminants (hydrophytes, silt,

- 3 -

1	Date	
2	minutes	Time, hours and
3		Object (ice edge, target cake, etc)
4		Direction of object, in degrees on horizontal vernier
5		Distance in km, as per distance scale
6		Distance between outside converging lines on grid, converted to m
7		No of graduations on scale of elevation
8		Value of one graduation on elevation scale, hm
9		Variable factor K
10		Distance to object km
11		Height of object, m
12		Distance the cake has floated, m
13		Time of observation of drift, seconds
14		Direction
15		Speed
16	Remarks	Components of drift

LOG FOR ICE OBSERVATIONS TAKEN WITH R. N. IVANOV PERSPECTOMETER

TABLE 12

sand, etc) or enclosed spaces (air bubbles), the translucent, the cloudy, and the completely clouded ice, opaque due to large amounts of contaminant and air spaces;

(b) determination of the thickness of the snow cover over the ice, and under certain conditions of its density;

(c) measurement of the thickness of the sludge below the ice; and

(d) description of characteristic processes involved in the growth, deformation, and thawing of the ice.

Systematic measurement of the thickness of the ice and snow, and of the submerged sludge, is performed in order to study the growth and thawing of the ice cover. Therefore, these measurements are taken daily at the beginning and end of the winter, while, in midwinter, when the ice cover has stabilized at more than 20 cm, the frequency of measurement is reduced to 6 times per month: the first, sixth, eleventh, sixteenth, twenty-first and twenty-sixth. The measurements are made at 2 spots on the ice which are always the same, a base point, and a supplementary point, which are chosen for the fact that they are undisturbed throughout the winter. These points must be at spots where there are no strong currents, flow-off of surface water, or the effects of other factors which might tend to distort the course of the natural growth and thawing of the ice.

These points must be on fast ice which came into existence at the test spot.

The base point is some distance out from shore, where the depth is over 2 m. The supplementary point is closer to shore,

but where the sea is deeper than the maximum thickness attained by ice in the given area. Should port hydraulics and other structures exist the supplementary point is fixed at one of their water-shed portions.

Observations of the thickness of the ice, snow and sludge are run during the entire period during which the ice cover is capable of sustaining the weight of a human being.

The points chosen should also be near the ice observation point or hydrometeorological station. Each time that a thickness measurement is to be taken, 2 holes, 30 to 40 m apart, are driven into virgin ice. After the thickness of the ice has been measured the holes are again packed with ice, and markers are frozen into them to prevent repeated use of those locations, as this would provide unreliable findings. One may also set up a permanent rod for systematic determinations of the rate of ice thickening and thaw.

The following may be used to drive or drill these holes: an ice-pick, a borer, GGI and GGI-47 ice drills, and hand-operated ice drills.

The ice-pick (Figure 23) is the simplest of the devices used to drive holes in ice, and consists of a wedge-shaped metal rod, 40 cm long, the top of which becomes a socket, 20 cm in length, in which a wooden handle is seated. The handle, thick at the bottom, becomes thinner toward the top, and has a ball-shaped tip to prevent it from slipping out of the hands. Greater security is provided if a hole be drilled below the ball tip, through which a loop of cord or thong is fitted, which is worn on the hand. A steel tip is welded to the point of the metal rod, the tip being sharpened by a file, when necessary.

Ice-picks may be of various designs, such as the bevelled form shown in Figure 24, the Chukchi-style chisel-shaped pick in Figure 25, or that with a round cross-section shown in Figure 26.

In breaking through the ice it is important that the walls of the hole be vertical, and not narrowed at the bottom. The sides of the hole should be somewhat conical in form only if the ice is more than 0.5 meter thick, while if thickness is greater than a m, steps are cut in the side, and the conical shape is considerably increased (Figure 27). This type of hole is rather like a prospecting pit. To remove the ice from a dry hole of little depth, an iron scoop shovel is used, or a pail if the depth is considerable. If the hole fills with water, the ice is taken out with a net (Figure 28), or an iron shovel with a sieve center (Figure 29).

A borer (Figure 30) is used if the ice is of considerable thickness, and it is difficult to make the hole with a pick. The borer consists of a steel tube about a meter long, with a diameter of 7 to 8 cm, and a wall thickness of 3 to 5 mm. The bottom of the tube has 10 sharp 12 mm teeth, elliptical in shape and facing a little outward.

The top of the borer consists of a massive, demountable metal head, somewhat below which 3 holes are provided. An iron bar is passed through 2 of these, which face each other, and is used to rotate the tool. The third is to permit escape of air. The borer is driven into the ground by a 4 or 5 kg sledge hammer, which is brought down on the metal head. After every few blows, the borer is taken out of the hole and cleansed of accumulated ice whereupon it is replaced in the hole with a finger over the

air-hole on the tube, and then quickly pulled out of the hole, which is thus cleansed of residual ice fragments.

About 40 minutes are normally required to bore a hole through 2 m of ice in this manner.

In work on very thick ice, a series of borers of varying lengths are required, short ones being used first, and longer ones as the hole gets deeper.

When the thickness of the ice cover exceeds 50 cm, ice drills are used with high effectiveness, in addition to the ice-pick and the borer. The drills now in widest use are the GGI, the GGI-47, and the hand ice drills used in polar seas.

The GGI ice drill (Figure 31) consists of a 10 cm drill and a metal handle fastened to the top of the drill. The drill bores through the ice under the blows of a sledge-hammer on the handle, which is rotated after each blow.

The GGI-47 ice drill (Figure 32) is of later design than that previously discussed. The GGI-47 drill consists of a brace and bit. It comes in 2 sizes. For ice up to one m thick there is a 105 cm bit, while for thicker ice the bit comes in a 200 cm length. The bit is of steel 40 mm in diameter with 120 mm pitch. The point of the bit is tempered. The work begins by fastening the brace to bit tightly by means of a bolt. Drilling is performed with the brace rotated at an even pace, and slight pressure on the handle. The rate of drilling is 0.3 to 0.4 m per minute.

The hand-operated ice drill (a large brace and bit) is usually used in polar ice (Figure 33). This drill is of steel, with a brace-holder of iron tubing, welded on. The handle has a

hand-held shovel midway in its length. Either one or 2 persons operate the drill, depending upon its sharpness, and the thickness and solidity of the ice.

(a) Measurement of the thickness of the ice in the hole is performed immediately after determination of the thickness of the snow cover. First the snow thickness is measured and then 0.3 to 0.5 m² of ice is cleared of snow whereupon the hole is driven. The thickness of the ice is determined by an ice gauge, which is lowered into the hole with care to keep it in a vertical position. The angled end is hooked under the bottom of the ice. The first reading is taken at the graduation of the gauge even with the bottom of a board placed on the ice and thus giving the thickness of the ice. The second reading is to determine the depth of water in the hole. This reveals how deep the ice is floating in the water. Both measurements are taken with care to read within one cm accuracy at 4 different points in the hole. The findings are entered in the corresponding column of the log. The same procedure is followed at the second hole which is 20 to 30 m from the first. Should the measurements in the 2 holes show marked divergence, readings are taken in a third hole. If the snow cover is considerable, the possibility exists that water may accumulate on the surface of the ice beneath the snow. The thickness of this layer of water is measured with the snow gauge and entered in the "Remarks" column of the log. In such a case, the thickness of the ice expresses the difference in the measured depth of immersion of its undersurface and the depth of the layer of water on the ice.

When these readings have been taken, the depth of the sea is determined.

In certain cases it is also necessary to know the distance

from the hole to the shore. Depending upon the purpose of the observations, the distance is measured in either way or is determined approximately by eye.

Various instruments, a description of which is given below are used to measure the thickness of the ice.

The sliding ice gage (Figure 34) consists of 2 parts: the primary long part divided into cm and having a transverse jaw at 90° , and a movable jaw sliding on the other. When the 2 jaws touch, the pointer attached to the movable jaw shows zero on the main section scale.

To measure the thickness of the ice, the fixed portion is immersed in the hole, and its jaw is hooked beneath the ice, while the movable jaw is then fitted closely to the top of the ice, which has been freed of snow.

The ice gage with angle brace (Figure 35) which is the type most widely used consists of a straight wood yardstick, 200 cm long (sometimes 230 cm), 6 cm wide and 2.5 cm thick. Both sides of the rod have scales, one of which is used to measure ice thickness, and the other, snow thickness. The zero point on the scale is 20 cm from the bottom of the rod which is faced with iron and is at the same level as the top of the angle brace which is hooked beneath the ice when measurements are made. The angle brace also of wood is fastened flush to the yardstick by screws. The cm markings are painted alternately white and black upward from the zero point. Every 10 cm there is a number marking. The other side of the rod also carries cm graduations on a scale 100 cm in length but reading in the opposite direction so that the zero point is at the top of the rod. This scale is designed to measure the thickness of the snow cover.

The collapsible ice gage (Figure 36) like that with an angle brace is in very wide use. It is a wooden cm graduated rule 115 cm long (250 for those to be used in polar hydrometeorological stations), 4.5 cm wide and 1.5 cm thick. A metal cross-piece which when in horizontal position, rests so that its top is at the zero point on the scale is 15 cm from the bottom of the rod. The metal piece rotates around a bolt and is actuated by a pullrod attached to it and held in place by 2 collars mounted on the rod. The top of the pull-rod is looped for ease in manipulation. The metal cross-piece is placed in the vertical position when the gauge is lowered and raised from the hole and in the horizontal for gripping the bottom of the ice.

The steel ice gauge shown in Figure 37 usually comes as part of a set with the G-I-47 ice drill previously described and is designed to measure ice thickness in the aperture drilled by that tool. The gauge is usually 105 cm long but is also made in a 200 cm length depending upon the thickness of the ice cover. The upper portion of the steel gauge terminates in a wooden handle. A bit lower there is a hilt to prevent the gauge from slipping through the hole in the ice. The bottom of the gauge has a support lever spring-actuated and a catch which engages the spring and holds the lever in a position normal to the gauge. One side of the gauge carries a cm scale, zero being even with the top of the spring-actuated lever when the latter is in the horizontal position. When the gauge is placed in the hole, the lever is held by the catch and thus parallel to the gauge. When the gauge is raised, the catch is released by striking the undersurface of the ice, and the lever thus braces underneath in a horizontal position.

The stationary ice gauge (Figure 38) is a rod within a tube frozen into the ice. 2 probes are attached at an angle to the bottom of the rod. One side of the rod is a graduated cm scale. It terminates in a handle at the top. To measure thickness the probes are immersed below the ice and readings are taken on the scale along the rod, at the graduation even with the top of the ice. Should the tube project above the ice the height of this portion of the tube has to be allowed for. Thus, the stationary ice gauge permits daily observations of ice thickness and eliminates the heavy labor involved in sinking new holes.

The ice thickness register (Figure 39) like the stationary ice gauge makes possible daily readings of ice thickness all winter long without heavy labor. Daily readings are of particular interest during the periods of growth and disintegration of the ice cover. The thickness register consists of a tube 2 to 3 centimeters in diameter and 3 m long. A piece of metal is fastened to the bottom of the tube and at right angles to it being held in place by a bracket. It carries 2 pulleys the purpose of which is to reduce the friction on a cable passing through the tube and carrying a hollow 20 cm glass float with a lift of 2 to 3 kg at its end. The other end of the cable with a pin fastened to it as pointer is fastened to the surface of the ice. The thickness of the ice is read off by means of the pointer along a vertical gauge set on the ice alongside the tube. The whole apparatus which rests on a wooden block at the surface is frozen into the ice. The tube is filled with kerosene to prevent water within it from freezing. When ice thickness measurement is taken the cable is unfastened, brought into fully vertical position and the float is allowed to rise to the undersurface of the ice. The displacement of the pointer relative to its initial position, which

is read off on the gauge at the beginning of the measurement, makes it possible to judge changes in the thickness of the ice. To prevent the float from freezing to the ice it is kept at some distance below except when measurements are under way. The readings are double-checked from time to time by digging a hole near the ice register.

The Georgievskiy floating ice gauge (Figure 40) is also a permanent device. It consists of a tube frozen into the ice containing a gauge with cable attached. The cable connects the gauge to a yoke with probes at both ends. Attached to the yoke are floats which move freely along the tube. Kerosene is poured into the tube to prevent formation of ice within it. When an ice reading is to be taken a dowel is removed from one of the holes in the gauge and the rising float carries along the cable and the gauge bar until the probes touch the bottom surface of the ice. The reading is taken at the gauge graduation which appears at the top of the tube. To prevent the probes from freezing in the ice the gauge bar is raised somewhat and held in place by a dowel. The tube is fastened to a cross-bar which is frozen into the ice. This facilitates maintenance of the apparatus in working condition until spring when the heating of the tube causes the ice around it to thaw with special rapidity. The surface thawing of the ice may be followed by the use of a simple attachment consisting of a small tube placed over the main tube frozen into the ice, the added tube carrying a lever arm and probe. The surface thaw is measured by determining the distance between the top of the main tube and the bottom of the second tube placed over it.

(b) Determination of the height of the snow cover, like observations of the snow content of the ice has the purpose of revealing the thickness of the snow, the nature of its various strata, the forms of snow formations on the ice (smooth or uneven

surface, drifts, sastrugi, etc), and is conducted before the ice thickness readings, i.e., while the snow cover is undisturbed. In addition to determining the time when the snow cover was formed (whether it is fresh or old), this data makes it possible to identify the period required for certain ice processes to take place, ice dynamics and the rate of growth of the thickness of the ice. Thus, if there is no snow on hummocks in winter, this is evidence that they are of recent origin, while a thick deposit of snow means that the ice formations thus covered are quite old. The direction of the sastrugi is a good indication of the prevailing winds and therefore of the drift. An anomalously large or small amount of snow over large areas of ice testifies to corresponding peculiarities in meteorological conditions which are of interest in ice prediction.

These observations to which little attention was paid in the past are now included in the program of work under all conditions: at hydrometeorological stations, in cross-sections taken when travelling, in shipboard and air-borne expeditions.

Determination of snow thicknesses by means of a portable wooden or metal snow gage, which is placed on ice having undisturbed snow cover at a point 3 to 5 m from where a hole is to be drilled in the ice. The gage are taken at various points in the vicinity of the hole, the average of these being recorded. The absence of snow at any of these points does not affect the manner of taking an average. All snow cover readings are entered in the corresponding column of the log.

A snow scale (Table 12) has been developed by the Arctic Research Institute to classify the snow cover. Use of this scale may be recommended for observations taken at the Hydrometeorological Service stations.

The portable wooden snow gage (Figure 41) is made of a smoothly planed stick of dry wood 180 cm long. It is 4 cm wide and 2 cm thick. The bottom of the gauge has an iron tip 5 cm long. The scale is in cm the graduations being of the same color as the numbers which represent tens of cm. Zero on the scale is at the base of the iron tip.

TABLE 13 SNOW COVER SCALE

Points	Description
0	No snow or occasional patches of snow
1	A thin uniform snow cover not over 5 cm thick or alternation of smooth snow cover and patches of bare ice constituting 30-70% of the surface in question
2	5 to 20 cm snow cover with small sastrugi drifts and sections of bare ice constituting 10-30% of the area in question. Drifts cover hummocks up to 50 cm
3	Deep snow cover, more than 20 cm on the average with no spots of bare ice and large drifts sometimes covering hummocks up to 1.5 m in height.

A metal snow gage (Figure 42) is used at polar hydrometeorological stations and in cases where the snow cover is so dense as to present considerable resistance to the wooden gage, which wears out rapidly as a result. It is sometimes impossible to get through the entire thickness of snow with the wooden gage.

The metal gage is of circular section and its cm graduation begins at zero which is at the point tip. The angled top of the gage is notched to carry a snow weight scale, which is suspended by a ring with the gage driven into the snow.

(c) The thickness of the sludge below the ice is measured by the ordinary ice gage, the sludge pole, or the Dobrynskiy or Groshev sludge gages. The sludge becomes visible as soon as the hole has been driven as individual lumps, the form of which is characteristic only of sludge, float to the surface of the water in the hole. The gage reading is taken at the moment when the observer, raising the gage, finds that it has become difficult to turn it in various directions, indicating that the angle bar of the gage has come into contact with the bottom layer of the sludge. The graduation on the gage corresponding to the water level in the hole is entered into the log book. The reading is done twice, an average being taken, rounded off to one cm.

The sludge pole (Figure 43) consists of a gage graduated to cm scale and having a hinged heavy iron rod bow at its bottom. When the pole is sunk into the hole the bow is swung upward and is in the same plane as the pole. To

determine the thickness of the sludge, the bow is brought into horizontal position by means of a thin cable held by 2 hooks running alongside the pole. It is then slid under the sludge. After the reading is taken the bow is lowered to its bottom position for removal from the hole. The reading, less the thickness of ice corresponds to thickness of sludge beneath the ice.

The Dobrynskiy sludge gage (Figure 44) is for measuring sludge of average consistency not over 4 m thick. The gage consists of a wooden pole about 5 m long and 5-7 cm in diameter, to which a pronged steel tip is fastened by screws. The tip consists of 7 flat fingers 40-50 cm long diverging at an angle of 20-30°. The gage is graduated by decimeters. The thickness of the sludge is measured by immersing the gage in the hole and raising it slowly until the prongs meet the bottom of the sludge, a point where further raising of the pole encounters some resistance. 3 or 4 readings with the prongs in various positions are averaged.

The Groshev sludge gage board (Figure 45) permits measurement of layers of sludge more than 4 m thick. It consists of a sheet of iron 100-150 m long, 10 cm wide and 2-3 cm thick. The end is pointed to permit dragging. Its own weight (up to 30 kg) enables it to sink readily through the entire layer of sludge. Holes are bored at each end of the board and cable, marked off every 0.5 decimeter is threaded through them. A ring through which a second cable passes is attached to one end of the cable at about 150-180 cm from the board. When the sludge gage board is lowered into the hole it is in a vertical position. To bring it into position below the bottom of the sludge it is moved into the horizontal position by evening out the ends of the cables. After the reading has been taken along the cable graduations the board is again moved into vertical position and removed from the hole in this manner.

(d) Characteristic processes typical of the thawing of the ice. Observations of the thawing of the ice from the surface begin with the appearance of the first signs of thaw and are usually

conducted once a day always at the same hour. The simplest device for determining extent of thaw is a wooden gage, painted white 25 to 35 mm in diameter and 2 m long frozen into the ice before thaw begins (Figure 46). A zero mark is made on the gage, level with the surface of the ice. Daily thaw is measured from this mark.

In taking a reading it is desirable to lay a board on the ice alongside the gage. The distance from the bottom of the board to the zero mark represents the daily thaw reported in cm.

To observe disturbance of the natural surface of the ice, dirtying it must be prohibited as must unnecessary walking near the gage.

The log should carry the date and time of the reading, the identification number of the gage, total thawing since the beginning of measurement, daily thaw, the thickness of the layer of thaw water at the gage, the color of the ice surface and various other observations.

9. Observations of Hydrometeorological Factors

Observations of hydrometeorological factors are made at the ice post a few minutes (5 usually) before the ice observations. Aside from a visibility report this consists of determination of the speed and direction of the wind and a description thereof (mild, intermittent, constant), its duration (when possible), and determination of factors of disturbance in accordance with regulations. Data on changes in sea level and the temperature of the surface layer of the water at the time closest to that of the ice observation is obtained from the log of the nearest adjacent hydrometeorological station. If the ice observation point is near

such a station and there is a lapse of not more than one hour between the ice and meteorological observations the wind speed and direction may be taken from the meteorology log.

[FIGURES]

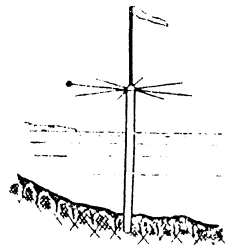


Figure 6. Orientation Post

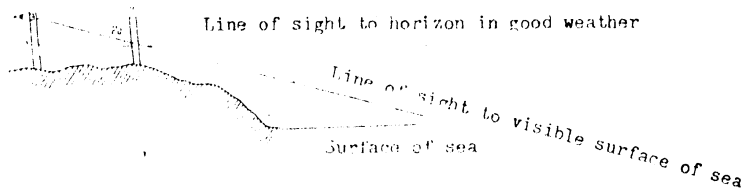


Figure 7. Rod Range-finder

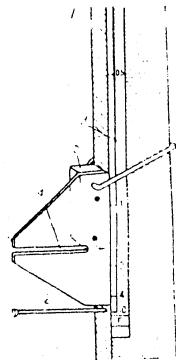


Figure 8. Forward Rod (I) of Rod Range-finder

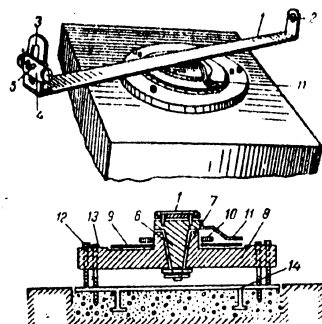


Figure 9. Vladimirskiy Angular Range-finder

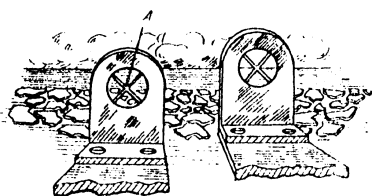


Figure 10. Method of Sighting the Angular Range-finder

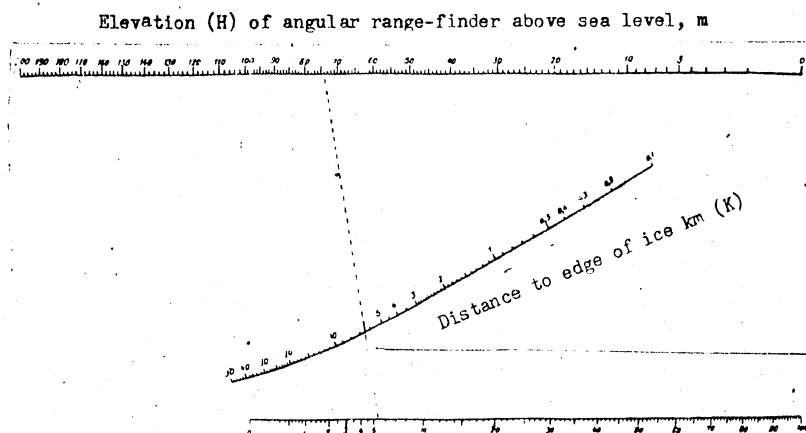


Figure 11. Melent'yev Nomogram

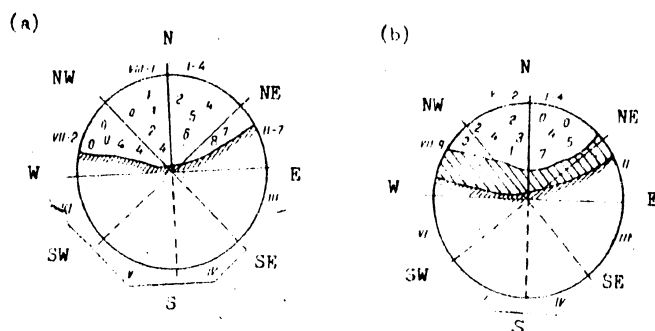


Figure 12. Ice-sketch Chart

(a) No fast ice; (b) Fast ice cross-hatched

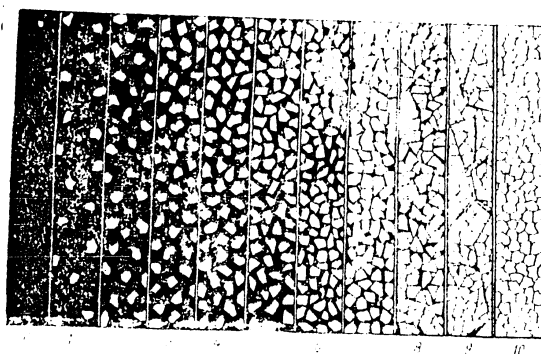


Figure 13. Ya. Ya. Gakkel' Ice-compactness Scale

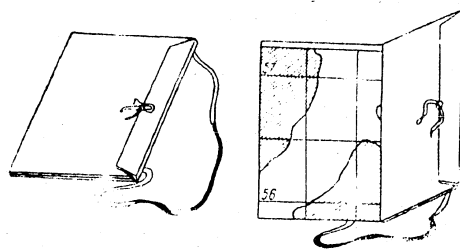


Figure 14. Ice-charting Map-board

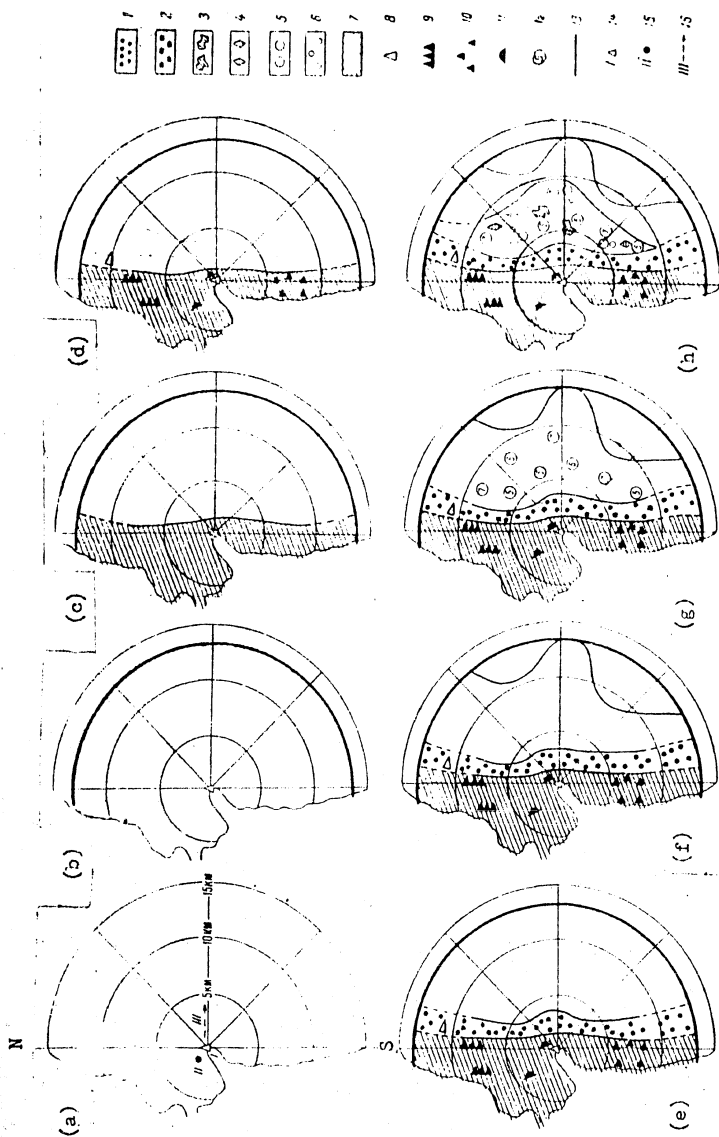


Figure 15. Procedure for Sketching Ice Conditions on Chart Blank

(1) needles, slush, sludge, snow sludge; (2) pancake ice (3 to 10 cm); (3) fields; (4) floes; (5) large cakes (up to 15 cm thick); (6) small cakes; (7) new fast ice; (8) icebergs; (9) fresh pressure ridge; (10) irregular hummocking; (11) stamulchi; (12) visible horizon; (14) ice observation point; (15) ice thickness measuring point; (16) direction in which width of fast ice has been measured

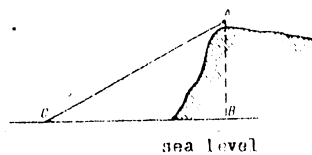


Figure 16. Determining of Distance from Cake to Shore

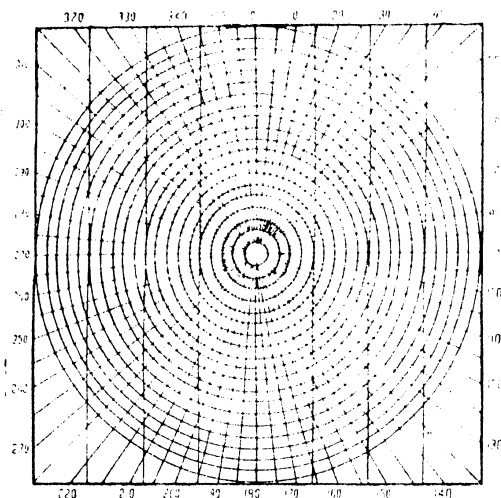


Figure 17. Radial Graph

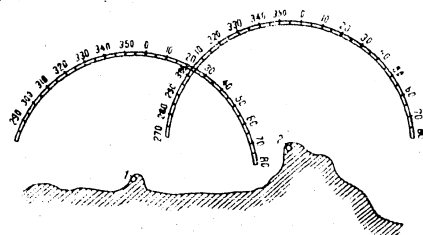


Figure 18. Determination of Position of Cake
From 2 Points on Shore

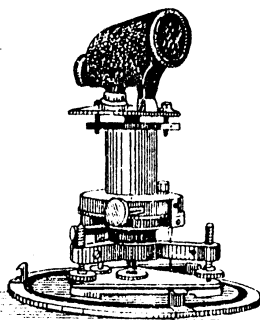


Figure 19
Ivanov Perspectometer

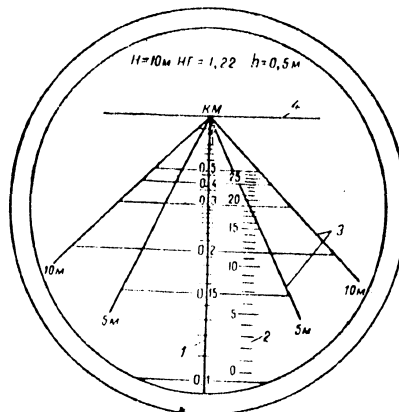


Figure 20
Perspective Grid

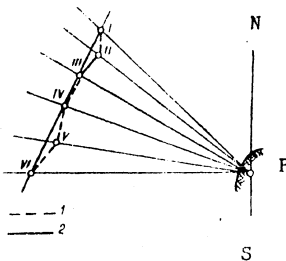


Figure 21
Determination of Ice Drift 1. actual
drift; (2) general line of drift

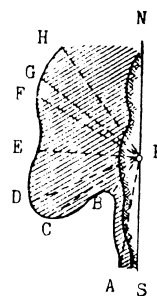


Figure 22
Fast Ice Edge Survey

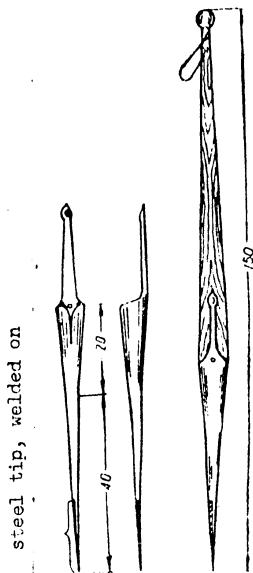


Figure 23. Ice-pick

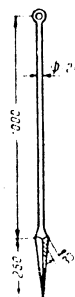


Figure 24. Ice-pick with beveled point

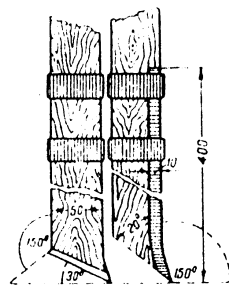


Figure 25. Ice-pick with chisel-type point



Figure 26. Ice-pick with point of circular cross-section

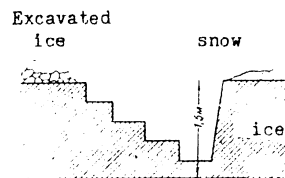


Figure 27 Digging a hole

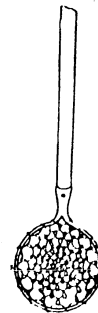


Figure 28 Net

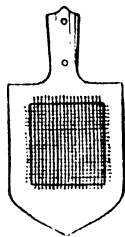


Figure 29. Sieve-center Shovel

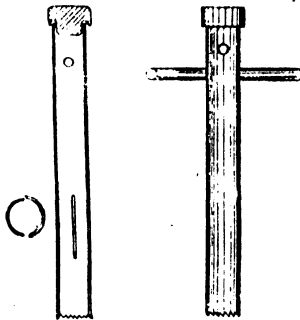


Figure 30. Borer

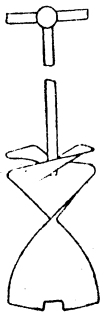


Figure 31.
GGI Ice Drill

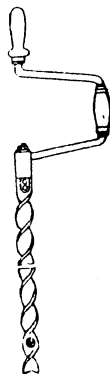


Figure 32. GGI-47
Ice Drill

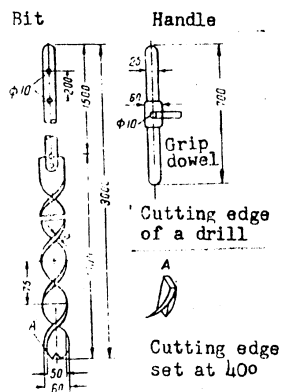


Figure 33. Hand-operated
Ice Drill

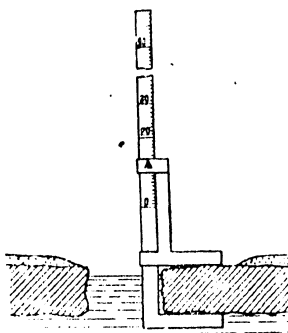


Figure 24
Sliding Ice Gage

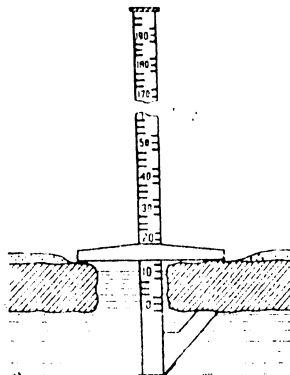


Figure 35
Angle-bar Ice Gage

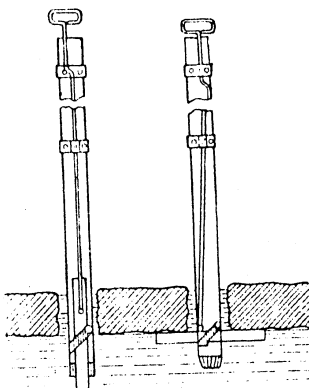


Figure 26
Folding Ice Gage

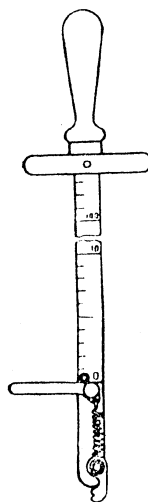


Figure 27
Steel Ice Gage

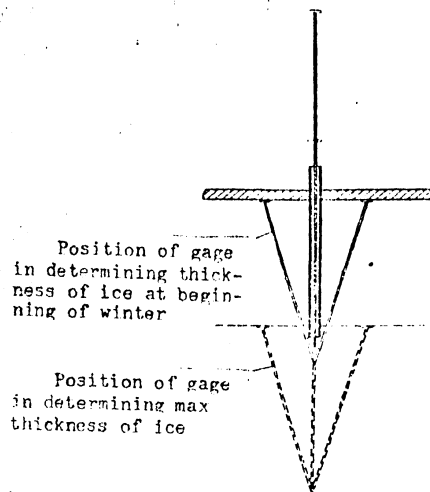


Figure 38

Permanent Ice Gage

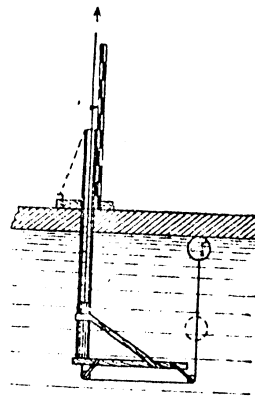


Figure 39

Ice Thickness Register

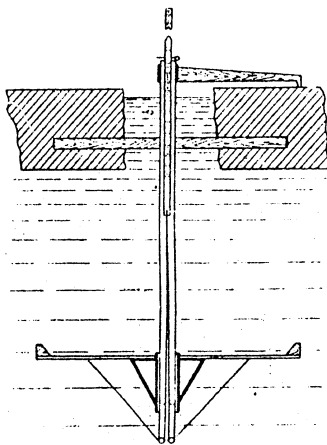


Figure 40

Floating Ice Gage

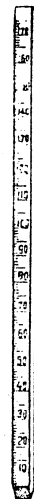


Figure 41

Portable Wooden Snow Gage



Figure 42
Metal Snow Gage

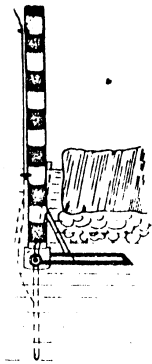


Figure 43
Sludge Pole

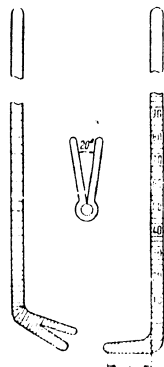


Figure 44
Dobrynskiy Sludge Gage

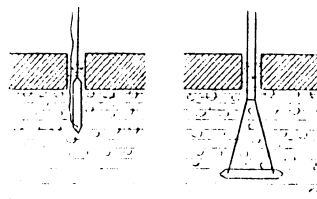


Figure 45
Graphex Sludge Gage Board

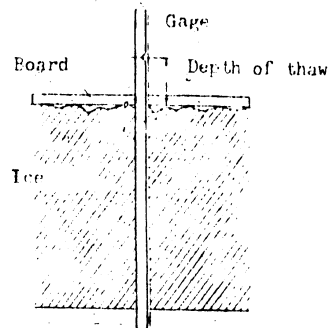


Figure 46

Method of Following Surface Thaw of Ice

[Pages 88-92]

The various types of observations made during expeditions over the ice each have their own specific characteristics. Below we present the procedures in the most important types of observations.

1. Studies of ice cover involve a description of the nature of the ice in the area under observation, measurement of its thickness, the taking of specimens for laboratory tests, and determination of ice structure.

In addition to description of the nature of the ice cover (level, hummocky, disordered hummocks, pressure ridges in particular directions, etc), symbols are used to enter on the map a fairly detailed description of the ice over a strip about 2 km wide.

Toward this end one notes: the median and maximum height of hummocks, other dimensions of hummock formations, leads and cracks, with their widths and directions, puddles, the dimensions of thaw water pools and open water caused by currents, expanses of open water, with indications of size, the state of the road for all types of transport, channels cut by icebreakers, etc.

In addition to the foregoing, observations of ice cover involve visual or semiinstrumental surveys, with investigation of the areas and conditions of formation of hummocks, ropaks, stamukhi, stranded pressure ridge, pressure ridges, bottom ice rafted ice, etc.

Measurement of the thickness of ice consists of determining its total thickness and, separately, that of the transparent layer and of inferior raftings, sludge, and the height of individual ropaks above the general level.

Specimens for laboratory study are taken by sawing out a block of ice. From this a column equal in height to the full thickness of the ice, and 5 to 10 cm across the base, is cut out by hack saw. This column is then cut into individual segments 1 to 10 cm high which are placed in containers with ground-glass plugs and sent to the laboratory for special studies, as described below.

To determine salinity, alkalinity, and the sulfuric acid content, 1.5 to 2 cubic decimeter specimens are taken from the same block, or 5 cubic decimeters when complete chemical analysis is desired.

To determine the ice structure, the thickness of the various layers in the block is measured with the centimeter rule. The total of the individual layers measured must equal the total thickness of the ice. The results of the measurements are entered into the corresponding columns of the ice cross-section log.

Ice is classified by structure as:

- (a) pure, transparent, usually blue or green, free of visible solid particles of hydrophytes, silt, sand, etc, and of air spaces;
- (b) translucent ice clouded due to the presence of many fine bubbles;
- (c) very cloudy ice, opaque due to the presence of many air spaces, and to various types of foreign matter.

These 3 types of structure are encountered in every conceivable combination. They may arise for different reasons, and be distributed variously within a single piece of ice.

Two particularly characteristic types of air spaces are found:

spheroids of true spherical or elliptical shape, or irregular forms of various types, showing a general uniformity of design in all dimensions. These spaces are characteristic of winter ice. They are classified by size into large spaces (1 to 10 mm in diameter) and small (0.1 to 1 mm).

Another type of space, the prozhilka ("vein," "fiber," "filament") is elongated, and usually originally a spheroid. This type is characteristic of the thaw period. They are sometimes quite long, and sometimes united into fine, thread-like spaces. They are always normal to the layer, i.e., vertical, and are 0.1 to 1 mm in diameter in the initial stage, but then becomes larger as the ice decays further, to become fine channels 1 to 5 mm or more in diameter.

As these canals become larger, the ice becomes friable and the crystals lose contact with each other, ultimately decaying.

2. Observations of snow cover involve a description of the nature of the snow cover in the area where the work is carried on, with determination of the thickness and density of the snow over the ice.

The thickness of snow is measured in a radius of 3 to 5 steps from each ice test hole.

Snow cover is classified as follows: fresh, sastrugi, firm, solid packed, solid frozen, single layer, multi-layer, crystallized but not frozen compact, compact frozen crystallized, fine or large-grained, loose powder, mounds and the directions of their crests, thawing, wet, water-permeated.

The thickness of the snow over a 3-km profile is measured at both ends and in the middle of the strip, and at additional points if it is more than 3 km.

Density is determined gravimetrically or volumetrically.

Gravimetric determination employs a portable snow scale. This consists of a metal cylinder, balance weights and a shovel (Figure 49). The cylinder, 60 cm in height, terminates at the bottom with a thick ring, 50 square centimeters in area, the edge of which is ground sharp. At the other end there is a handle and ring by means of which it is suspended from the balance. The face side of the cylinder bears a centimeter vernier. The balance consists of a rule divided into 2 unequal arms by a knife-edge support. The long arm, carrying a grooved metal weight, is divided into 5 cm graduations. The metal cylinder is suspended from the end of the short arm.

Before each weighing, the balance is tested by being brought to equilibrium. This should set in when the zero marking on the vernier is seen through the hole in the weight, 1, and when a check line on the pointer 2, permanently fixed to the rule, corresponds to one on the hanger. If this does not produce equilibrium, the weight is moved along the arm until it is obtained, and the reading at this point is taken as zero in weighing. The whole balance is then lowered into the snow, by means of the sharp bottom edge of the cylinder, until it touches the earth at which point the thickness of the snow is read off on the vernier on the outside of the cylinder. Before the cylinder is raised from the snow, the shovel is forced beneath it, to prevent any of the contents from escaping. The cylinder is turned upside down on removal, snow adhering to the outside is removed, and it is weighed.

If the snow is greater than 60 cm in thickness, i.e., thicker than the height of the cylinder, its thickness is determined section by section and the results are then totalled.

The weight of the specimen in grams will equal the number read on the balance arm multiplied by 5 (that being the value of each graduation). In cm^2 the volume of the specimen will equal the reading on the scale multiplied by 50 (the area of the cylinder base).

Thus, the density of the snow is expressed in terms of the ratio of the weight of the sample to its volume, i.e. $\sigma = \frac{P}{V}$.

In ice density studies, attention is also given to the ice crust in the snow deposit. The thickness of the crust is measured and an appropriate supplementary entry is made in the log book.

If the density meter described above is lacking the density of the snow is determined volumetrically. A specimen of known volume is thawed and the volume of water obtained therefrom is determined by means of a graduate.

Here the density of the snow is expressed by the ratio of the volume of water to the volume of snow, i.e., $\sigma = \frac{V_1}{V_2}$. Given data on the thickness of the snow layer and its density, one may calculate the water supply it contains: $H = \sigma h$.

Water density is also measured by means of the volumetric snow meter (Figure 50) consisting of a brass or zinc cylinder carrying a cm scale. The top of the cylinder bears wooden handles solidly mounted on a metal rod passing through holes in the cylinder. In the bottom of the cylinder there is a slot cut halfway through its perimeter, and serving to seat a valve 3. The valve slides freely into the cylinder slot. It is grooved halfway round its perimeter and is equipped with a handle.

The bottom area of the snow meter cylinder is 100 cm^2 .

Accessory equipment for the volumetric snow meter consists of 2 pails with tightly-closed covers and a graduate beaker.

Calculation of snow density is facilitated by the use of the Table for Determination of Density of Snow Cover which gives the density of snow to an accuracy of 0.01 on the basis of the readings on the cylinder scale and the rule of the snow density meter weights.

To calculate the density of the snow by means of the volumetric snow meter, the cylinder reading is multiplied by 2. Then, finding the value thus obtained, and that representing the reading in the beaker with the thawed snow, the density of the snow is read off in the Table accordingly.

It has been found that wet snow falling in large flakes has a density of more than 0.5. The density of fresh snow fallen when the temperature is slightly below freezing is close to 0.1. At lower temperatures, and in the absence of wind, density declines to 0.05-0.03.

3. Hydrological observations along the ice strip under study are made in accordance with special programs and usually consist of measurements of the depth of the sea, determination of water temperature in the ice hole, notations on current, and salinity sampling. In rare cases there may also be observations of the swell of the sea which sometimes appears in ice-free areas (beyond the fast ice), or may be judged by fluctuations in water level in the ice hole due to the dissemination of waves from the open sea beneath the ice cover.

These studies are accompanied by meteorological studies of the strip consisting of observations of the general state of the weather, determination of the velocity and direction of the wind,

and of air temperature. Meteorological observations are made at the base point of the strip and are then repeated every 2 hours until all work thereon has been completed.

Observations of fluctuation in level must be run on a closer schedule along the shore and parallel to the ice studies, in the area of the study.

All ice and snow observations on the strip are entered into a special log for the recording of ice and snow on ice, while hydrometeorological observations go into the corresponding logs.

In addition to log entries, the work on the strip includes sketches of the nature of the ice surface, and other data on the state of that surface. Note is also taken of all special features surrounding the observations such as may serve as supplementary data in the analysis of the entire complex of observations on the ice.

The field data on ice and snow thicknesses is then used to plot a cross section of the ice field on mm-ruled graph paper. The horizontal scale chosen must be such as to permit the total length of the drawing to be embraced within 25 to 30 cm. Thus, if the strip under study is a km long a scale of 50 m per cm is convenient, while for a 10 km strip a scale of 500 m per cm is desirable etc). The axial horizontal is the base from which the snow depth is plotted vertically above it and the ice depth below it. The points thus entered are connected by lines, the upper of which represents the snow cover along the entire strip, and the lower represents the thickness of the ice. Foreign matter on the ice is also shown in the corresponding scale. The horizontal line shows the azimuth of the profile and the identifying numbers of the points corresponding

to the numbers of the stations (holes) in the ice. In addition, the thickness of the ice and the height of the snow cover, the number of the strip and of the research party, the date of the observations, the coordinates of the initial and final stations (holes), and the horizontal and vertical scales, are also shown on the profile.

The drawing must be signed by those who drafted it and by the chief of the hydrometeorological station or the field party.

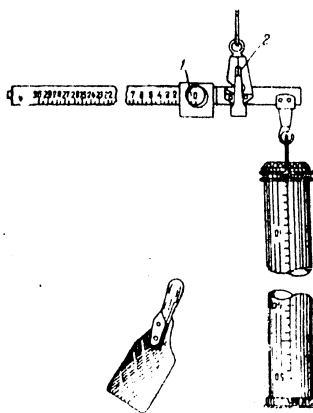


Figure 49

Gravimetric snow m

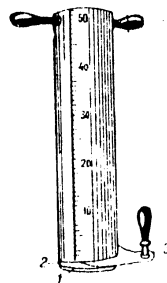


Figure 50

Volumetric snow m

[Pages 92-115]

CHAPTER VI

ICE OBSERVATIONS FROM SHIPBOARD

All vessels make ice observations during the duration of the ice season. These observations include:

- (1) types of ice;
- (2) boundaries of fast ice and open water;
- (3) consolidation of drift ice;
- (4) ice forms and the state of the cover;
- (5) navigability of the ice;
- (6) supplementary descriptions of the distribution of the ice and the state of the ice cover;
- (7) observations of the thickness of the ice and snow;
- (8) hummocking, and the heights of hummocks;
- (9) compression and opening of the ice;
- (10) ice drift;
- (11) ice mapping; and
- (12) hydrometeorological factors.

Observations 1 to 9 above are made from the flying bridge, the height of which is entered in the journal.

Ice and snow thickness studies, and determination of hummock heights when the vessel is tied up, or during drift with the ice, are made directly from the ice by the methods set forth in the preceding chapters.

Ice drift observations may be made from the vessel, when not in motion, or directly from the ice.

Ice mapping, i.e., the rendering of sketches while the vessel

is under way or drifting, and determination of hummockiness by the point scale is done from the flying bridge, and governed by changes in the ice panorama.

All shipboard ice observations are accompanied by hydrometeorological observations, of which the most important have to do with visibility, the rate and direction of the wind, and the state of the surface of the sea.

The further elaboration of ice observations from shipboard require supplementary navigation data including copies of the shipboard watch logs, maps with the course of the vessel, data on verification of the ship's compass, etc.

Observations of the ice by the ship's company on merchant vessels are made at the same time as hydrometeorological observations: 0, 4, 8, 12, 16 and 20 hours and at intervals between these, if marked changes in ice conditions be noted. Note is also taken of time of approach to, entry into, and leaving the ice, the general direction of the ice edge being noted accordingly.

Special ships (icebreakers, vessels carrying expeditions, and ice patrol vessels), make virtually continuous ice observations, in any case not less frequently than within a radius adequate for reliable determination of ice compactness, in other words, 0.5 to 1.0 nautical miles.

All ice observations are entered into the shipboard hydrometeorological log.

Certain components of the ice situation to wit: ice types, the boundary between fast ice and open water, compactness of drift ice, determination of the forms of ice and of the state of the ice

cover are identified in a manner analogous to observations from the shore, but with due regard to the specific conditions governing observations on the open sea. The navigability of the ice, i.e., the degree to which the ice may be penetrated by ships, is determined by a combination of factors including ice forms, consolidation (coverage), thickness, hummocking, and the height of hummocks, mechanical and physical properties, state of disintegration, state of closing or opening and drift.

Direct observations of the listed factors and recording of the speed of the ship through the ice as well as the speed of the ship's engines enter into determination of penetrability of a given ice area for a given vessel, a matter of great importance to ice navigation.

The simplest of the existing scales by which the passability of ice to ships is determined by eye, is the 4-point scale compiled by the Arctic Research Institute (Table 14).

TABLE 14

SCALE OF NAVIGABILITY OF ICE BY SHIPS

Points	Conditions of Ice Navigation
1	Ice readily navigable by given type of vessel which does not have to change course and shows virtually no decline in speed.
2	Ice presents complications for navigation by given type of vessel which proceeds at reduced speed and headway, with changes in course
3	Ice navigable by given type of vessel with difficulty. Progress is by forcing the ice.
4	Ice impassable to given type of vessel, which is incapable of moving under its own power.

Several types of ice navigability scales are in use in the Hydrometeorological Service. The first of these was developed in 1931 by V. V. Timonov and N. N. Gaken (Table 15).

TABLE 15

NAVIGABILITY SCALE FOR VESSELS PROCEEDING ALONE OR LEADING CONVOYS
IN DRIFT ICE

Points	Conditions of Ice Navigation
0	Vessel proceeding through open water, or as if water were open.
1	Vessel makes slight changes in course, avoiding large cakes.
2	Vessel maneuvers between cakes, occasionally changing speed.
3	Vessel performs sharp maneuvers, speed changing from forward to stop and reverse, and smashes ice bridges.
4	Vessel advances, barely holding its course, changing speed, bucking, and advancing very slowly.
5	Progress is solely by bucking and advance is measured by ships' lengths.
6	Efforts to advance are unavailing.

In these scales, the penetrability of the ice is measured by a point unit which identifies the difficulties encountered by the particular vessel in its progress through the ice. The unit of penetrability is based on the existing ice conditions, and note is made of whether the vessel is moving independently or is being convoyed by an icebreaker. The compactness of the ice and its median form during the period of the given observation is entered simultaneously in the corresponding column of the log.

The scales adduced provide only a qualitative evaluation of the passability of the ice, while, for operational purposes, it is exceedingly important that there be at least an approximate evaluation of the absolute speed of the vessel through the ice. To meet this need, the Arctic Research Institute proposed a nine-point scale (Table 16).

TABLE 16

ICE NAVIGABILITY SCALE

Points	Description
0	Vessel navigates ice at same speed as open water.
1	Vessel navigates ice at better than 5 knots
2	Vessel navigates ice at 3 to 5 knots.
3	Vessel navigates ice at 2 to 3 knots.
4	Vessel navigates ice at 1 to 2 knots.
5	Vessel navigates ice at 0.6 to 1.0 knot.
6	Vessel navigates ice at 0.3 to 0.5 knot.
7	Vessel navigates ice at 0.1 to 0.2 knot.
8	Vessel progresses at a rate measurable in ship's lengths per watch.
9	Vessel brought to a standstill by severe ice conditions, and can make no further progress.

Four years of studies by the National Institute of Oceanography in the White and Baltic Seas since the war resulted in the development of a scale of maximum speeds for vessels of various classes and types per point unit of ice navigability. This was developed by V. L. Tsurikov. They are presented in a 7-point scale (Table 17).

This scale envisages 5 types of wooden and metal ships, classified as follows:

(a) wooden sailing vessels with auxiliary engines of up to 300 hp, with no ice shielding, reinforcement, or hull lines designed for ice navigation;

(b) wooden sailing vessels with auxiliary engines of up to 300 hp with ice shielding, reinforcement, and hull lines designed to resist ice squeeze;

(c) metal steam and motor-driven vessels, with engines of 50 to 800 hp, and freighters of 800 to 6000 hp, without ice shielding, reinforcement, or hull lines for ice; and freighters with reinforcement and 300 to 6000 hp engines but lacking ice shielding; also sea-going tugs of 300 to 1800 hp, not specially equipped for navigation in ice;

(d) freighters of 800 to 3000 hp with reinforcement and ice shielding; steamers and Diesel vessels equipped for ice-breaking, and having 800 to 6000 hp; icebreaker tugs of 300 to 800 hp with hull lines for ice and reinforcements; and icebreakers of 800 to 1800 hp with and without bow propellers;

(e) icebreakers of 1800 to 10,000 hp with and without bow propellers; 3000 to 10,000 hp icebreakers with bow propellers; steam ice-cutters of 3000 to 10,000 hp.

[See page 77 for Table 17]

A second scale developed by Tsurikov (Table 18) describes the navigability of ice to vessels under icebreaker convoy.

This scale provides for 3 types of convoys, depending on the number of vessels: I more than 3; II small convoys of 2 ships; III a single vessel under convoy including tow by a short line.

TABLE 17

ICE NAVIGABILITY SCALE FOR VESSELS OF VARIOUS CLASSES SAILING ALONE OR CONVOYING OTHERS

Points	Description of Ball Unit	Speed of vessels of various classes, as % of open water speed				
		<u>Wooden ships, class</u>		<u>Metal ships, class</u>		
		a	b	c	d	e
1	Ice readily navigable by any vessel					
2	Ice readily navigable for self-propelled vessel capable of navigation in ice, but presents difficulty for other ships with metal hulls. Sometimes impassable for wooden ships without ice shielding	80-100	80-100	80-100	80-100	80-100
3	Ice readily navigable for icebreaker, but difficult for ordinary vessel equipped for ice navigation. Navigable only under convoy for other metal ships. Impassable for wooden ships without ice shielding	NI-80	NC-80	25-80	65-80	65-100
4	Icebreakers navigate with some difficulty. Other metal ships can navigate only in convoy. Impassable for other ships	NI	NC-65	NC, CO	5-75	30-100
5	Icebreakers navigate with difficulty. Other vessels equipped for ice navigation can proceed only in convoy. Impassable to all other ships	NI	NI, NC	NC	NC, CO	5-75
6	Icebreakers navigate by ramming. Other vessels equipped for ice navigation can proceed only in convoy. Impassable to all other ships	NI	NI, NC	NI	NC	up to 35
7	Ice impassable to all ships	NI	NI	NI	NI	NI

Note: NI, navigation impossible; NC, navigation only under convoy; CO, navigation by crushing only.

TABLE 18
PASSABILITY SCALE FOR SHIPS UNDER ICEBREAKER CONVOY

Points	Description of Point Unit
I	Vessels may navigate by themselves (without icebreaker convoy).
II	Vessels may navigate a channel previously opened; if under icebreaker convoy, large convoys may pass.
III	Large convoys are difficult and uneconomical, but 2 to 3 vessels may follow an icebreaker at over 300 m.
IV	2 to 3 vessels may follow an icebreaker at more than 300 m. Ships are occasionally nipped and have to be broken out.
V	An icebreaker may be followed by 2 to 3 vessels only if they are in close formation. If the spacing is increased to 300 m, the lead vessel is immediately nipped and has to be broken out.
VI	Only one vessel may be convoyed at a time, and then on a short towline.
VII	Convoying is impossible, as a ship cannot follow an icebreaker even on a short towline, although the icebreaker itself is able to move.

If it is impossible for icebreaker convoy to proceed, the appropriate notation is made in the log.

The major shortcoming of these scales of ice navigability for ships under icebreaker convoy, lies in the fact that they describe not the penetrability of the ice, but that of a channel dependent upon properties of the vessels convoying and being convoyed. Unfortunately, lack of data made it impossible for V. L. Tsurikov to determine the rate of speed of convoys in these various navigability point classes:

Ice navigability data is entered in a special journal, the title page of which bears the name of the vessel and other essential data: the sea being navigated, the date on which the observations

began and ended, the time zone, the name of the captain, and of those making the observations. The log should be made up of ledger-size sheets in 20 columns (Table 19).

When vessels are in narrow waters, the ice observations should be written out in words. Column 3 is for the general true course, which is taken from the navigation chart on which it is plotted. Column 4 shows the mean speed of navigation along the general course, in knots. Column 5 shows the speed of the vessel in knots, relative to the ice, when the vessel is in constant motion. All speed data relative to the period of observation are noted, and the average is then taken. Columns 6, 7, 8 and 9 are for characterization of engine function, assuming a four-screw vessel. If the given vessel has less than 4 propellers, the excess columns are crossed out.

If the observations are from a steamer, the steam pressure and screw revolution per minute are entered in these columns. If a Diesel electric vessel is involved, the volts and amperes of current in the engine circuits and the propeller revolutions per minute are entered. In preparing the log blanks, space is provided for the foregoing under the general caption for the 4 columns under discussion, "Engine Records."

The ice forms are entered in column 10 with the median form above and the remaining forms below a horizontal line.

Column 11 is for the extreme dimensions of the predominant type of cake and it is desirable, when possible, to note the extreme dimensions of each type of cake.

Column 12 is devoted to a description of the consolidation, or specific coverage of ice. If this is not uniform in the various

directions, the average value is given, and supplementary consolidation data is provided in column 19.

Columns 13 and 14 are for ice and snow thickness measurements, the mean thickness being entered above a line, or underlined.

Hummockiness, on the 5 point scale, is entered above a line and the height of hummocks in m is entered below it both in column 15.

Column 16 serves to record compression and opening out of the ice. If this phenomenon is not uniform over the visible surface of the sea, or if it follows a clearly-defined direction, additional remarks are entered in column 19. The point scale in use is specifically stated.

Column 17 shows the penetrability of the ice in points according to one of the existing scales. The indication of the scale used is obligatory.

Column 18 is for the final findings of certain meteorological components (direction and speed of wind, visibility and temperature of the air) which have a direct effect on the condition of the ice. The data for this column are entered in the meteorology log.

Column 19 serves for all supplementary data not going into the preceding columns and characterizing hydrometeorological and ice conditions which shed light on the conditions of ice navigation and the passability of ice by a vessel. Entries in this column may be in whatever form the observer desires or it may be used for sketches and similar purposes.

The last column, 20, is for remarks and addenda by persons elaborating the material in the log or subjecting it to critical examination.

The supplementary descriptions of ice distribution and the state of the ice cover are obtained as a result of examination of the entire visible surface of the sea by the naked eye or by binocular. These data are entered in the appropriate columns of the logs.

Shipboard observations and entries should include the following:

- (1) whether the ship is in open water or ice. In the latter case, in what type of ice;
- (2) in what areas the sea is covered with fast ice, and the direction of its edge;
- (3) unusual aspects of the distribution of the drift ice;
- (4) polynias, leads and channels, with data as to dimensions and location;
- (5) floebergs and stamulchi, with indications of number, dimensions, nature and location;
- (6) water sky and ice blink, and the directions in which they are seen;
- (7) piles of ice ashore, with height and shape;
- (8) disintegration or hummocking of fast ice, and closing or opening of drift ice.

In addition to the foregoing, everything that describes the strength and navigability of the ice cover is noted as is the functioning of the icebreakers and the convoying of vessels, i.e., data from vessels encountered on route as to difficulties in ice

navigation, ice communication, use of the ice for the laying of roads, tracks, airstrips, etc.

Various methods are used to determine the ice and snow thickness along a vessel's course. The simplest consists of eye judgment of the thickness of cakes which are often forced up edgewise alongside the ship. The snow cover over the sea ice packs may form a very dense mass. It may be frozen to the ice. However the boundary between them is very clearly seen when cakes stand on edge.

When the vessel is moving at low speed, ice and snow thickness may be measured by means of a round pole painted alternately black and red every 10 cm.

A hook on the bottom of the pole is engaged beneath the ice, whereupon a reading is taken of the marking even with the top of the cake.

These measurements are more accurate if a wooden rod 50 cm long and 7 to 10 cm wide is cast on the ice. It is fastened to a line.

One of the major shortcomings of these methods lies in the fact that ice and snow thickness are determined from the deck of the ship rather than from the captain's bridge. Most of the other ice observations however are made by a single person who is usually on the bridge and is compelled frequently to climb down to the deck for this other purpose.

The method of measuring the thickness of ice and snow directly from the wing of the captain's bridge is described below. First it is necessary to determine the height of the observer's eye

above the surface of the ice. The height of the bridge above the current water line may be obtained from the ship's plans to which the elevation of the observer's eye above the deck is added. Due to the change in actual water line as the vessel consumes fuel and water, the elevation of the observer's eye above the water must be rechecked constantly as the ship navigates in ice.

P.A. Ponomarev on the icebreaker "Yermak," used the following method of measuring the thickness of ice and snow. A rod gage 80 to 100 cm long with decimeter graduations painted alternately white and black (Figure 51) was mounted beneath either or both wings of the bridge at the level of the upper deck. It must be absolutely horizontal, and normal to the side of the ship. It is sighted against the background of the edges of upturned cakes which permits the thickness of the cake to be determined in proportion to the graduations on the gage. Greater accuracy is obtained if each graduation on the gage is somewhat less than 10 cm as it is closer to the eye of the observer than to the cake. This magnitude is found by the formula

$$H = \frac{H_e - H_r}{H_e} 10 \text{ cm} = \left(1 - \frac{H_r}{H_e}\right) 10 \text{ cm}$$

in which H is one graduation, H_e is the elevation of the observer's eye, and H_r the elevation of the gage above the ice.

At night, the point of observation is lit in such a manner as to illuminate the rod and the cake to be measured. To make allowance for changes in the ship's draft during a voyage, a special table is compiled, from which corrections are made for different drafts.

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1	Date and local time, hrs and min
2	Location of vessel
3	General true course (in degrees)
4	Rate of navigation along general course (knots)
5	Rate of speed relative to ice (knots)
6	Left
7	Middle
8	Right
9	Bow
	Revolutions per min
	Voltage
	Amperes
	Engine performance
10	Ice forms predominant other
11	Dimensions of nearest cake, m
12	Consolidation of ice, points
13	Thickness of ice predominant other
14	Snow thickness, cm predominant other
15	Hummockiness, in points Height of hummocks, in m
16	Closing and opening of the ice (identify scale used)
17	Navigability of ice (identify scale used)
18	Weather
19	Additional data
20	Notes on examination and elaboration of foregoing, signed

TABLE 19

Another simple method of measuring the thickness of the ice and snow while the vessel is under weigh consists of the use of the range-finding grid of an artillery binocular (Figure 52). The ocular of this type of binocular has a grid with large graduations, corresponding to 0.01 of the distance from the eye to the object to be measured and small graduations every 0.005. On this basis, the thickness of the ice and snow is calculated on the formula

$$h = 0.001nH_e$$

in which h is the thickness of the ice and snow, n is the reading on the binocular reticule, and H_e is the elevation of the observer's eye above the ice.

Ice and snow thickness are read off on the binocular grid only when the cake selected is precisely at its nadir relative to the observer. The error in reading is 0.01% of the elevation of the eye, i.e., when the bridge is less than 10 m, it is one cm.

B. I. Arnol'd-Alyab'yev invented an illuminated gage to measure ice and snow thickness at night, and also when a vessel is moving at high speed. It consists of a slotted piece of wood, A (Figure 53), 120 cm long, with a cross-bar, B. Wooden rollers C are fastened to both ends of the cross bar. They support the gage against the side of the vessel when it is lowered from the bridge. There are holes at D to suspend the gage (Figure 54). Four electric bulbs, taking their current off the ship's circuit are housed in the hollowed interior of the gage. Frosted glass, with decimeter graduations painted black at every other graduation, covers the top and sides of the gage. The bottom of the gage bar remains uncovered to illuminate the ice.

The accuracy to which ice and snow thickness are determined by the Arnol'd-Alyab'yev shipboard gage is one to 2 cm, when the

ice is 10 to 15 cm thick, and 2 to 3 cm when it is 20 to 40 cm thick.

The advantage of this type of shipboard gage lies in the ability to make observations at night, directly from the bridge of any type of vessel, i.e., from the same point as that from which all other ice observations are made.

V. I. Arnol'd-Alyab'yev also invented with S. M. Andreyev, a portable instrument consisting of a flashlight projecting a special scale on the cake to be measured (Figure 55). The battery used to feed the apparatus is housed in a shoulder carrying case, the brightness of illumination depending on the strength of the light source, and the accuracy with which the scale is projected on the surface being dependent on proper focussing of the objective. The value of the vernier graduations varies with the elevation of the instrument above the ice. These data are carried in a table attached to the instrument. A shortcoming of the instrument is that it can be used only during the Polar night.

All the foregoing methods of measuring ice and snow thickness while the vessel is under weigh have as previously indicated some deficiency. To meet these deficiencies, V. L. Tsurikov and I. L. Pervakov invented an instrument which permitted not only measurement of the thickness of ice and snow, but determination of the width of cracks in ice, the horizontal dimensions of small cakes, etc. This instrument consists of a metal bar, 1, 60 cm long, to one end of which a bracket 2 is affixed, carrying a short tube 3, parallel to the bar (Figure 56a). A collar 4, carrying a stop screw 5, and bearing a metal frame 6, within which is mounted a 14 x 22 cm rectangle of plexiglass moves freely along the bar. A rectangular grid with graduations every 2 cm is applied to the plexiglass, one

of the squares being further graduated at 2 mm intervals (Figure 56b). The bar has graduations every cm from a zero point coinciding with the end of the tube which is used as eyepiece. The ice and snow thickness are measured from the bridge wings, the spardeck or the main deck, by measuring the number of spaces on the grid occupied by the cake seen through it. The value of each space on the grid in cm will thus be $2 \frac{H_e}{l}$ in which H_e is the eye elevation of the observer and l is the distance from eye to grid.

The distance between eye and grid is selected with consideration of the elevation of the observer in such fashion as to facilitate mental calculation of the number of squares. Allowance is also made for the draft of the ship. The position of the grid is changed whenever the draft changes by more than 20 cm. The number of divisions on the grid corresponding to the projection is counted at the moment the target cake is at the nadir. 10 to 20 cakes should be measured at each determination of ice and snow thickness, the mean thickness then being recorded. The frequency of measurements depends upon the problems to be faced. As a rule determination of ice and snow thickness is made every hour during National Institute of Oceanograph expeditions. Should sharp changes in thickness occur, the interval is reduced to 20 or 30 minutes. Check tests of this method have shown that it is accurate to within 3% of the thickness of the ice under measurement.

In all ice thickness measurements, it is also desirable to note the strength of the ice (friable, viscous, etc) and its gross structure (monolithic, porous, stratified).

When a vessel is at a standstill in the ice, or drifting with the ice, all thickness measurements for ice and snow are performed by the methods and instruments described in the section

on shoreside ice observations. Should a vessel be at a standstill for long periods in ice less than 20 cm thick, the thickness is measured daily at noon. When the ice is over 20 cm thick, it is measured once in 5 days.

Determination of hummocking and the height of hummocks from the ship is performed in accordance with the appropriate point scale, and the Ivanov perspectometer, as previously described.

If no perspectometer is available a naval range-finder may be used. With it, distance to a hummock may be measured in cable lengths which are then converted to meters by means of a table.

The height of the hummocks is determined by means of an artillery binocular. The distance to the hummock is counted on its grid. For the purpose the formula $h = 0.001 nl$ is used. h is the height of the hummock, and n is the reading on the grid in thousandths of 1.

If no range-finder is available, hummock height is measured only when the vessel approaches within a few m. The mean height is found by observation of 15 to 20 hummocks which are compared from the most convenient spot from the vantage point of the vessel's deck.

No method has been devised to measure the submerged part of the hummock which is of great importance in determining the navigability of ice. V. I. Arnol'd-Alyab'yev has found on the basis of certain actual measurements that the buoyancy of a hummock, i.e., the ratio of its visible to invisible portions is approximately 0.5 to 0.25 on the average. Taking the average density of the visible portion of a hummock as being equal approximately to 0.5 and measuring its height and width one may

thus measure the weight of its invisible portion, which will be:

$$P_1 = \rho \frac{1}{2} B H_1 L$$

where P_1 is the weight, ρ is the density, B the breadth, H the height, and L the length, or $P_1 = \frac{B H_1}{4}$ tons per linear m of hummock (ridge).

The ratio of the weights of the sub-surface and visible portions of a hummock depends upon the specific gravities of ice and sea water.

$$P_1 = \frac{P_2 \delta}{\Delta} - P_2 = P_2 \left(\frac{\delta}{\Delta} - 1 \right)$$

from which one obtains

$$\frac{P_1}{P_2} = \frac{\delta - \Delta}{\Delta}$$

in which P_1 is the weight of the visible portion of the hummock, P_2 is the weight of its invisible portion, Δ is the specific gravity of the sea ice, and δ is the specific gravity of sea water.

The specific gravity of sea ice usually fluctuates between 0.7 and 0.9. Thus in salty sea water, the $\frac{P_1}{P_2}$ ratio may fluctuate between $\frac{1}{4}$ and $1/7$ which is valid for individual hummocks, in which the elevation of the visible and invisible portions is approximately the same. Hummocks in the ice cover have a sub-surface width considerably larger than their surface above the water (due to the considerable thickness of underthrust strata). The visible portion of the hummock or pressure ridge usually rests on this underthrust ice, which is why the $\frac{H_1}{H_2}$ ratio comes to only $\frac{1}{4} - \frac{1}{2}$.

The methods, far from satisfactory, by which the underwater height of a hummock is measured simultaneous with the height of its visible portion includes the use of a disc to measure the transparency of the water. The disc is lowered from the vessel by sounding line.

One of its edges is then maneuvered beneath the portion of the hummock sitting deepest in the water. A reading of the line is taken at the moment when the disc disappears beneath the hummock. This method gives satisfactory results in measuring compact hummocks of monolithic structure, floating alone.

Stanukhi are measured by determining the depth of water around them.

In observing hummocks it is suggested that note be taken not only of their height and the depth of the invisible portion below the water, but also the type of hummock, the direction of pressure ridges, the age, and general hummockiness of the ice.

Observations of the closing and opening up of the ice are made visually, by means of a scale developed in 1932 by the Maritime Department of the Hydrological Institute, and supplemented by the National Institute of Oceanography as a result of observations during recent years (Table 20).

Closing of the ice is understood to mean the process of solidification in which slob ice is pressed into shape, squeezed and hummocks formed with resultant difficulties of navigation (sometimes bringing vessels to a standstill or even destroying them). By opening of the ice is meant a decrease in consolidation. This is accompanied by partial settling of hummocks and the parting of large cakes the space between them becoming filled with slob ice. Opening of the ice permits even rather weak vessels to progress fairly readily.

Occasionally one still hears the northern seaboard phrase "the ice is being mowed." This means that closing or opening is progressing in various directions, with the result that if no

observations had been taken prior to the onset of this phenomenon it is difficult to decide which process is actually underway.

In 1953 an Interdepartmental Commission recommended the use of the following gradations of characteristics in observations of ice closing and opening, the recording of these phenomena being formalized thereby:

- (1) very close ice;
- (2) close ice
- (3) fluid ice, i.e., ice of 8 to 10 point consolidation beginning to separate after closing and
- (4) opening ice: ice the compactness of which is declining.

TABLE 20
SCALE OF ICE CLOSING AND OPENING

Points [1]	Characteristics [2]	Signs [3]
1	Rapid opening	Ice consolidation declines by a point or more per hour. Recently-formed hummocks, which have not had time to freeze solid, sink back.
2	Average opening	Ice consolidation declines, but not as rapidly, the rate being less than one point per hour. Level fields of ice develop cracks. The channel behind an icebreaker widens rapidly.
3	Slight opening	Leads open very slowly, sometimes at a rate invisible to the eye. Cracks appear in ice rind covering leads. Slob ice squeezed together comes apart. Ice moves away from the side of the ship. The channel behind an icebreaker widens.

[1]	[2]	[3]
4	No visible change	No signs of closing or opening in an hour's time
5	Slight closing	Leads narrow every so slightly. Rind in cracks becomes compressed and the slob ice begins to undergo compression. The channel behind the icebreaker narrows slightly.
6	Average closing	Leads close noticeably and the consolidation of the ice increases less than one point per hour. The slob ice becomes compressed. The channel behind an icebreaker closes quickly.
7	Rapid closing	Ice consolidation increases one point or more in an hour. Hummocking occurs in the consolidated ice.

There are times when it is difficult to discover whether the process occurring is closing or opening. In such instances, the journal entry reads "closing or opening." Should other factors (darkness, fog, etc) make it impossible to determine the reason, the entry reads "not established," and if no changes in closing and opening are noted, the entry reads: "No noticeable change."

Observations of indistinct closing and opening during National Institute of Oceanography expeditions on the White Sea were made by means of artillery binoculars, a panoramic tube or a shipboard ice gage. The method employed which was proposed by V. L. Tsurikov, involves observations on the closing and opening of the ice from aboard a ship drifting at the edge of a lead, and also in the ice.

In the former instance, the observer, N, uses the reticule of his artillery binoculars C, to calculate the distance between the 2 points A and B on the opposite side of the lead and a target on the ice presented by a single ropak, a pressure ridge or an

appropriate case (Figure 57). On repeating the reading after a period of time, the distance between points A and B is increased if the lead widens or decreased if it lessens. In the former case, the distance between the points increases and they take on a new position (A' and B'). Thus, when the lead widens, the angle ANB declines, and vice versa, when it narrows that angle increases, a fact that is reflected accordingly in the binocular reading.

In the second case, the ship, drifting in the ice, is surrounded by a number of leads (Figure 58) the width of which is measured from the highest point on the ship (the captain's bridge, the top, etc). When this is the measurement the width of the lead will be: AB, CD, EF, GH. After a brief period has elapsed, a repeat observation from the same point (Figure 59) makes clear that the width of the first lead has widened and become not AB, but A'B. The widening of the lead results in an increase in the angle ANB as well, the result being A'NB. Opening and closing in other leads is determined analogously.

The state of the ice rind and slob ice in the leads is a very good index of closing and opening.

When closing or opening occur, the ice rind, as the thinnest type of ice is that most readily destroyed, so that opening produces cracks, while in subsequent closing, individual pieces of ice rind, crushing into each other, form the characteristic toothed effect.

In closing, slob ice becomes packed so tight as to be able to sustain the weight of a man.

The degree of closing of ice is very well characterized by the scale in Table 21 used by the Arctic Research Institute for observations in the high Arctic, where powerful compression creates areas where ice may be navigated with difficulty if at all.

TABLE 21
SCALE OF ICE COMPRESSION

([Note] Compression is a factor recorded only for ice showing 9 to 10-point consolidation and not younger than gray young ice, i.e., thickness is not less than 15 cm if this last type of ice predominates).

Points	Description
0	Ice "on the move" (This phrase means that ice of 9 or 10-point consolidation has begun to show motion prior to opening).
1	Weak closing. In the compression zone, small patches of open water may be seen. There are occasional fracture hummocks, and stratification of young ice. Broken ice is squeezed onto the edges of cakes as a result of the general packing.
2	Marked compression. The individual leads in the compression zone tend to close. There is hummocking where the ice is weaker and at junctions between fields. Stratification of young ice occurs. Broken ice piles up into a solid mass and bulges forming ridges ("pillows"). Heavy ice has not been found to hummock.
3	Solid compact compression. There is intensive hummocking of winter ice which also affects polar ice in part. Ridges of broken ice form everywhere. The young ice is chiefly hummocked.

In the high Arctic the possibilities of navigation decline with the increased packing of young ice, particularly if this occurs where it is intermixed with winter or polar ice. Therefore, a special 5-point scale (Table 22) has been introduced for this ice, to facilitate evaluation of the degree to which the residual ice present in the fall has frozen together. These observations are made from the day that stable ice formation begins. Descriptions of the development of the ice cover, without point indication, is

made, of all signs of ice formation and of further development until stability has been attained.

TABLE 22
FREEZING SCALE

Points	Description
0	No signs of freezing
1	Elementary forms of ice: slush, sludge, snow sludge, appear among residual ice.
2	The surface of the water between residual ice is completely covered with primary ice forms (slush, sludge, etc), while ice rind may be seen in places.
3	Ice rind predominates in the types of young ice seen among accumulations of residual ice. Young grey ice may be seen in spots. The residual cakes freeze into ice fields.
4	Young gray ice predominates among the young ice formed amidst accumulations of residual ice. Gray-white ice begins to appear in spots. Level ice begins to appear everywhere.
5	Gray-white ice begins to predominate among the accumulations of residual ice. White ice appears in spots. The ice cover takes on its typical winter form and consists of fields of level ice for the most part.

Observations of the drift of ice moved by wind and currents of various speeds and in various directions may be made. In summary form for a particular period of time, by determination of the coordinates of a vessel drifting with the ice. Should the vessel be standing at anchor, these observations are made visually, for the most part, the appropriate scale (Table 9) being used.

While the ship is drifting in the ice within the limits of

visibility of the shore or in the open sea, navigational, radio-navigational, and astronomical determinations of its position must be made systematically. The accuracy and frequency of these determinations of the coordinates of a drifting vessel governs the accuracy and reliability of data on drift obtained by elaboration and analysis of this data.

Accurate plotting of the course of a drifting vessel on a large-scale chart makes it possible to calculate the direction and rate of drift for any desired period of time. To study the principles of drift, it is necessary in addition to make more frequent wind observations. It has been found in practice that highly interesting and valuable drift data may be obtained if observations are carefully pursued not only by special drifting expeditions but by vessels accidentally nipped by the ice. In following drift, it is also necessary to pay attention to discrepancies in the planning and gathering of all supplementary navigational data (compass correction, etc) needed in the processing of material.

In addition to systematic determinations of the location of a drifting vessel, it is necessary to make direct observations of drift by use of the sounding-lead. This is done as follows.

The lead is lowered from the ship's winch or from a reel. As soon as it touches bottom a stop-watch is started. The length of line h is measured, and slack is immediately paid out, so that as the drift proceeds the cable continues to unreel from the drum. When a certain amount of time has passed, which depends upon the depth of the spot and the rate of drift the winch is stopped and further paying out of the cable ceases. When the cable is again tense, the stop-watch reading is noted. Now the length of the

cable paid out l and the angle at which the cable deviates from the vertical is noted. When the values of h , l , t , and have been obtained or even only some of them (h , l , t or h , t , ...), various mathematical means may be used to calculate the rate of drift during the period of observation. This is usually done on the formula

$$v_{\text{knots}} = K \frac{h_1 \text{tg}}{t} = K \frac{dt}{t}$$

in which K is 1.942, the conversion factor from meters per second to knots and h_1 is the depth of the sea in meters, with the addition thereto of the elevation of the pulley or reel above sea level:

$h_1 = h + g$, h , tg being the total drift during t seconds, or d_t .

Table 23 presents depths and slacks for a lead line paid out from a ship. To obtain the rate of drift, the value found on the table is divided by t seconds.

K. V. Burakovskiy's nomogram (Figure 61) is used as follows to calculate the rate of drift. The depth measured h , is plotted on the bottom scale h_1 , from which a vertical is drawn on the right side of the figure, to intersection with arc 1, corresponding to the length of cable paid out. A horizontal line is drawn from the point of intersection until it intersects the vertical scale d_t , where the magnitudes of drift for t seconds are given. Armed with this value we turn to the left side of the nomogram on which the d_t value is plotted on the corresponding scale. A straightedge is then used to connect this point with the figure representing the number of seconds during which the cable was paid out as found on scale t . The point of intersection of the straightedge and the intermediate scale, v , gives us the desired rate of drift in knots.

Simultaneous with the observations of rate of drift, one

determines its direction (within 5° accuracy). This is done by means of a ship's compass or an instrument for measuring angles. Pointing the zero on the vernier of such an instrument at the bow of the vessel, and finding an orientation parallel to the plane of the diameter, one finds the dihedral angle, between the diametric plane of the vessel and the vertical plane passing through the sounding line overboard. In determining drift from the starboard side, the direction will be: true course $+ 180^{\circ} + \dots$, while from the port side it is true course $+ 180^{\circ} - \dots$.

In addition to the progressive movement of the ice, it is important to know the rotation of drift ice around its vertical axis.

Observations of rotation are particularly important in a period when a vessel frozen into the ice, imitates all the motions of the latter and drifts with it as a unit.

Rotatory motion is due to the friction of ice with the shore, with the adjacent field and with ice massifs. Irregular winds and currents are capable of having a major effect on the rotation of the ice. Observations of rotatory movements such as those made by Ya. Ya. Gakkel' during the drift of the S. S. Chelyuskin in 1933-1934, require no more than systematic readings of the compass course on the ship's main compass. The frequency with which such observations need be made depends upon the rapidity with which there is change in the compass course. If change occurs from hour to hour, observations should be made at that interval. Observations of rotary motion should be accompanied by reasonably frequent checking of the compass itself, as deviations in a magnetic compass occurring with change in magnetic latitude can produce significant distortion in the observations and conclusions therefrom.

The corrected compass courses entered on the chart in a given scale make it possible to determine the direction and speed of rotatory movement of the ice.

Ice mapping, that is, sketching of the ice conditions as they change along the course of the vessel, or periodically during its drift, is conducted during the entire period of observation. Outline maps of the given sea are used for this purpose. 1:1,000,000 and 1:1,500,000 maps suffice for description of the general ice conditions in the sea, while maps on a significantly larger scale are needed for detailed ice reporting, and the convoying of vessels through the ice.

The course of the vessel as shown on the navigation chart is entered on the outline maps or tracing sheets (Figure 62). (This is usually done somewhat after the last previous plotting of course when the correction course has been entered on the chart. Prior to this, the ice situation is drawn in rough draft.) The beginning of each 24-hour period is noted by entering the date. The entire ice situation is entered in symbols along the plotted course of the vessel, the limits of visibility being indicated. Changes in ice conditions and the time when they were noted are also indicated. It is of particular importance to sketch in changes in the compactness (coverage) of ice and the general outline of the ice edge. It is important to note the time when the drift of the vessel begins and ends, the drift proper being indicated by an irregular line.

All supplementary data, notes and descriptions of the ice situation are entered on blank places on the outline chart or tracing sheet, and appended to the observation journal.

Observations of hydrometeorological features are conducted parallel to the ice observations conducted from the vessel, and are inextricably interwoven therewith. Of particular importance in ice observations are studies of wind components, visibility, and waves. Visibility from the ship is determined in the same manner as from the shoreside ice point, a 9-point scale being employed for this purpose. The elevation of the observation point from which the observations are made is of high importance. Usually, all ice observations from a vessel, and visibility notes are made from the captain's bridge. In some cases the top of the crow's nest is used in which case it is essential to record the elevation of these points in the log.

The direction of the wind is determined by means of the ship's compass (with allowance for inclination and deviations), and its rate, by anemometer. The true value of both magnitudes, with correction for the speed of the vessel, is arrived at by graphic plotting or by the circles of Rudowitz, Druzhinin, or similar methods. If waves and swell are noted during a voyage, particularly near the ice edge, this is of marked significance, and it is therefore essential to look out for this, and note it in the log. These records are kept on a point scale for direction and strength of wind and wave.

TABLE 23

DETERMINATION OF RATE OF DRIFT BY MEASURED ELEVATION (FROM WINCH
PAY-OUT SCALE TO OCEAN FLOOR) AND SLACK OF SOUNDING LINE. (LENGTH
AND SLACK IN M)

Elevation	Slack				Elevation	Slack			
	10	20	30	40		10	20	30	40
[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]
10	34	54	75	95	72	76	111	139	165
11	35	56	77	97	74	77	112	141	167

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]
12	36	58	78	98	76	78	113	143	168
13	37	59	80	100	78	79	114	144	170
14	38	60	81	101	80	80	116	146	172
15	39	61	82	103	82	81	117	147	174
16	40	63	84	104	84	81	118	148	175
17	41	64	85	105	86	82	119	149	177
18	42	65	87	107	88	83	121	151	179
19	43	66	88	109	90	84	122	152	180
20	43	67	89	110	92	85	123	154	182
21	44	68	90	111	94	85	124	155	184
22	45	70	92	113	96	86	126	157	185
23	46	71	93	114	98	87	127	158	185
24	47	72	94	115	100	88	128	159	188
25	48	73	95	117	105	90	131	163	192
26	49	74	96	118	110	92	134	166	196
27	49	75	98	119	115	94	136	170	200
28	50	76	99	120	120	98	139	173	204
29	51	77	100	122	125	98	142	176	207
30	51	78	101	123	130	100	144	179	211
31	52	79	102	124	135	102	147	182	214
32	53	80	103	125	140	104	149	185	217
33	54	81	104	127	145	105	151	188	219
34	54	82	105	128	150	107	153	190	222
35	55	83	106	129	155	109	156	192	225
36	56	83	107	130	160	111	158	195	228
37	56	84	109	131	165	112	160	198	231
38	57	85	110	132	170	114	162	201	234
39	58	86	111	134	175	115	164	204	238
40	58	87	112	135	180	116	166	206	241
41	59	88	113	136	185	118	169	209	244

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]
42	60	89	114	137	190	119	171	211	247
43	60	89	115	138	195	121	172	214	250
44	61	90	116	139	200	122	174	217	253
45	61	91	117	140	210	124	178	221	258
46	62	92	118	141	220	127	182	226	264
47	63	93	119	142	230	130	186	231	268
48	63	94	119	143	240	133	190	235	272
49	64	94	120	144	250	136	193	238	277
50	64	95	121	145	260	138	196	242	282
52	66	97	123	147	270	140	199	246	287
54	67	98	125	148	280	142	203	250	292
56	68	100	127	149	290	145	207	255	297
58	69	101	129	151	300	147	210	259	302
60	70	103	130	153	320	152	216	266	310
62	71	104	131	155	340	156	222	272	317
64	72	106	133	157	360	159	227	279	325
66	73	107	134	159	380	164	233	287	333
68	74	109	136	161	400	168	238	294	342
70	75	110	138	163	420	172	243	301	350

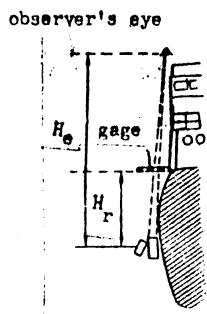


Figure 51. Method of measuring ice thickness by boom-gage

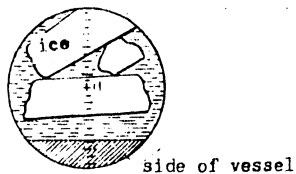


Figure 52. Method of measuring ice thickness by artillery binocular

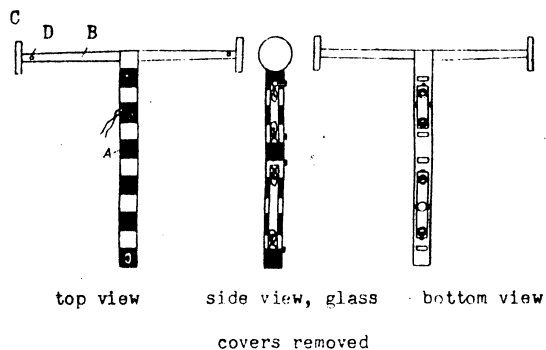


Figure 53. Shipboard gage, Arnol'd-Alyab'yev type. A: beam; B: cross-bar; C: rollers; D: holes

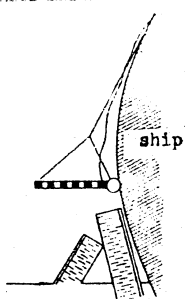


Figure 54. Arnol'd-Alyab'yev gage in working position alongside ship

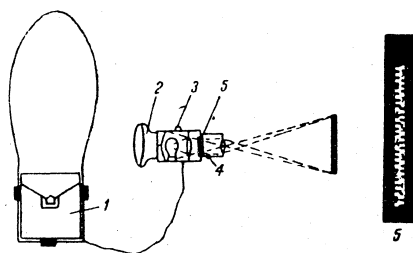


Figure 55. Andreyev apparatus. (1) Battery carrying-case; (2) handle; (3) switch button; (4) focussing spindle; (5) projected scale

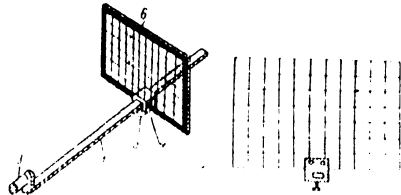


Figure 56. General view of shipboard ice gap.

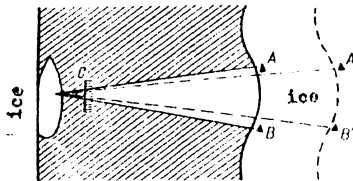


Figure 57. Opening of ice. Vessel drifting at edge of lead.

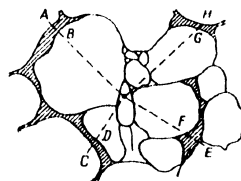


Figure 58. Leads around vessel drifting among cakes

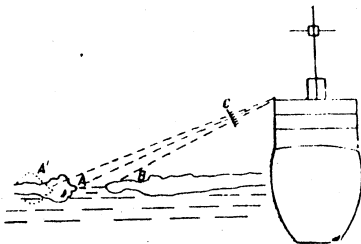


Figure 59. Opening of ice. Vessel drifting among cakes

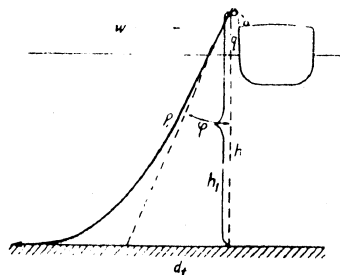
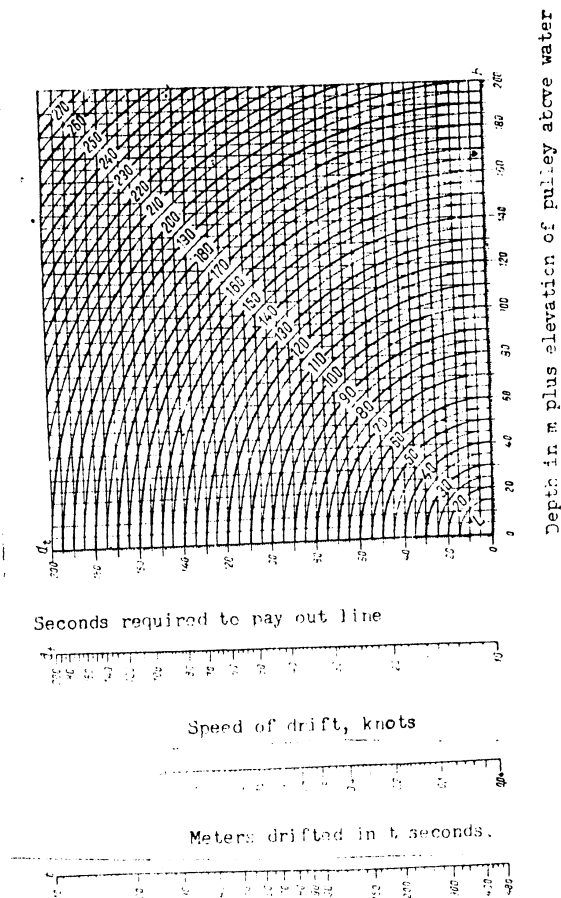


Figure 60. Determination of ice drift from vessel frozen in ice



Note: No correction for sag of line

Figure 61. Nomogram for calculating rate of drift

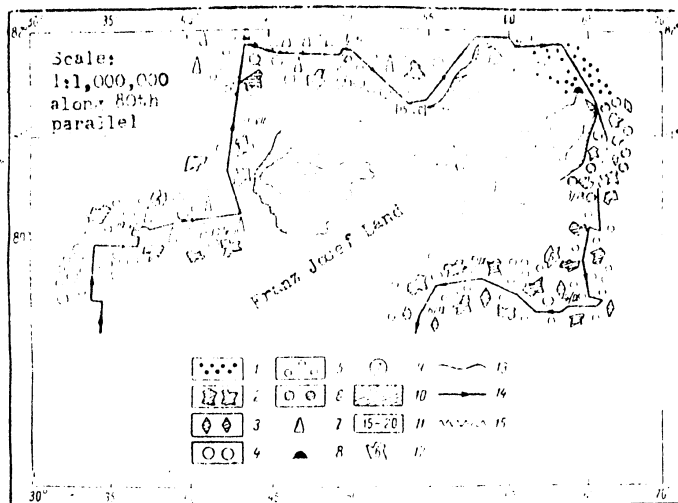


Figure 62. Ice mapping from a ship. (1) needles, slush, sludge, snow sludge; (2) fields; (3) floes; (4) large cakes (to 15 cm thick); (5) small cakes; (6) large cakes, 15 to 30 cm thick; (7) icebergs; (8) stamukhi; (9) consolidation index; (10) fast ice; (11) thickness of ice, cm; (12) number of fields in points; (13) ice edge, fast ice edge, boundaries between areas of identical consolidation (isonoints); (14) ship's course; (15) ship's drift.

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CHAPTER VIII

OBSERVATIONS OF THE PHYSICAL AND MECHANICAL PROPERTIES OF SEA ICE

In studies of sea ice researchers are interested not only in the external signs of the state of the ice cover and the changes in these signs in time and place, but also in the chemical, physical and mechanical characteristics of the ice indissolubly bound up with the foregoing. Study of ice in this fashion is important not only for a fuller and more all-sided understanding of the ice regime of various seas, but is also of independent interest, as the physical and mechanical properties of ice have much significance to the design and stress analysis of hydraulic engineering.

Study of the physical and mechanical properties of sea ice are a rather new branch of research in the USSR, which began for all practical purposes, after the Great October Socialist Revolution and is to this day pursued on an inadequate scale. To some degree this is a reflection of the considerable difficulties encountered in this type of research.

At present, various methods of determining physical and mechanical ice indices under field conditions have been devised.

Below we describe some of the methods in widest use.

Physical Properties of Sea Ice

Of the physical parameters of sea ice those most frequently determined under field conditions are density, air space content, temperature, and thermal expansion.

1. The density of ice is one of its most important characteristics,

in terms of a number of theoretical questions having to do with ice, and particularly for practical reasons. The density of sea ice depends on temperature, the salt content contained between the ice crystals, and the content of air and water bubbles.

The experimentally-determined formula for the density of pure freshwater ice without air bubbles is expressed by the following formula:

$$\rho_I = \frac{\rho_0}{1 + 0.000165t}$$

in which ρ_I is the density of ice at the given temperature, ρ_0 is its density at 0° , and 0.000165 is the mean volumetric coefficient of the thermal expansion of ice. It follows from this formula that the density of freshwater ice declines as its temperature increases.

The temperature dependence of sea ice is more complex, as the salt solution contained between the ice crystals affects its thermal expansion as the ice temperature changes.

If the sea ice was initially of low temperature and salinity, its density declines with rise in temperature. If, however, sea ice was initially of high temperature and salinity, further increase in temperature would result in an increase in its density. Changes in the density of sea ice in connection with changes in temperature are relatively small and do not usually exceed 0.01.

The density of sea ice varies with salt content within wider limits, particularly at high temperatures. Thus when the temperature of ice is -2° and its salinity is 2% its density is 0.924 while at the same temperature and a salinity of 15% it is 0.953.

The relationship of ice density to the air or gas-bubble content is expressed by the following formula:

$$\rho_I = \rho_0 \left(1 - \frac{n}{100}\right)$$

in which ρ_0 is the density of ice free of air bubbles, and n is the porosity of the ice i.e., the ratio of the volume of air or gas bubbles found in the ice to total volume, expressed in percentage.

Under field conditions the ice density is usually determined either by hydrostatic weighing, or by a method developed by V. V. Shuleykin.

The hydrostatic method consists of weighing the same pieces of ice, 200 to 600 grams in weight, in air and in kerosene (Figure 64). Before weighing, the kerosene temperature is determined and its density () found on a table for this purpose.

The ice temperature is taken to be that of the air in the room (or the thermostatically-controlled chamber) in which the ice is kept for an extended period prior to the test. To avoid changes in the ice temperature it must be weighed fairly rapidly.

The density of the ice is calculated on the formula:

$$I = \frac{P}{P - P_1}$$

in which P is the weight of the ice in air, and P_1 is its weight in kerosene.

Shuleykin's method consists of determining the volume of a floating piece of ice on the boarder between 2 liquids of differing density. A piece of ice 200 to 250 grams in weight is lowered into a vessel (Figure 65), filled with water on the bottom and kerosene at the top. The piece of ice floats on the boundary surface between the 2 liquids. There are 2 openings in the vessel. One is in its lower portion and the other somewhat above the mid-line. Three to 5 mm glass graduate tubes are fused to the openings and act as gages. The vessel is filled with water to somewhat below the upper

opening. Readings on the graduate tubes (to an accuracy of 0.01 cm) of the levels of the 2 liquids before and after the ice is immersed permits the density δ_I to be calculated on the formula:

$$V_1 \delta_1 + V_2 \delta_2 = (V_1 + V_2) \delta_I$$

in which δ_1 and δ_2 are the densities of the water and kerosene, respectively and V_1 and V_2 are the volume of the particles of ice immersed in the water and covered with kerosene. V_1 and V_2 may be expressed by the difference between the levels of the liquid before and after immersion into the ice and by the cross-section of the vessel.

The final formula for ice density calculation looks as follows:

$$\delta_I = \delta_1 \frac{a}{b}$$

in which δ_1 is the specific gravity of the water in the lower portion of the vessel a is the difference in the readings of the water level and b is the difference in readings in the kerosene level.

The temperature of the water and ice are determined in the same manner as in hydrostatic weighing.

2. The spaces in ice like its density, constitute a parameter of the highest importance in characterizing sea ice.

The cavities in ice affect its density, strength, and conductance as well as its optical and other properties.

The cavity content of ice is determined by the volume of air it contains as bubbles emitted during the thawing of a given piece of ice of known weight. The volume of this air is measured by special instruments. In the USSR the instruments in widest use

are those developed by V. I. Arnol'd-Alyab'yev and V. V. Shuleykin.

The Arnol'd-Alyab'yev instrument (Figure 66) consists of a glass beaker a thick-walled glass bell with ground-glass neck, and a burette having a cock at the bottom and a bulge in its upper portion. This bulge collects the gas emitted during thawing of the given piece of ice.

The piece of ice, weighed at the outset is placed beneath a bell in the beaker which is filled with kerosene or turpentine. The bottom of the burette is fitted into the neck of the bell. The burette is then filled with kerosene by suction from the beaker containing the piece of ice under test, and the cock is closed. As a result of the thawing of the ice, the air from the spaces in the ice accumulates in the upper part of the burette. After the ice thaws completely and the intake of air ceases, the air volume V is counted off in cubic cm on the burette. The height of the kerosene or turpentine column in the burette and consequently the volume of the spaces in the ice specimen depends upon:

- (1) the pressure of the gas in the space between the cock and the meniscus of the liquid;
- (2) the external air pressure;
- (3) the weight of the column of liquid from the level in the glass to the meniscus;
- (4) changes in the volume of the burette under the pressure of the external temperature.

The first 2 factors are covered by a factor of correction:

$$K = \frac{H}{760 (1 + \alpha t)}$$

in which H is the atmospheric pressure at the moment of reading and t is the air temperature in the burette, i.e., the temperature of

the building in which the test is made while α is $1/273$ the coefficient of thermal expansion.

The sign of the correction for the weight of the column of liquid K_1 , is opposite to that for K and is calculated on the formula

$$K_1 = \frac{h\bar{\sigma}_t}{H_p(1 + \alpha t)}$$

in which H_p is the normal pressure in grams, and $\bar{\sigma}_t$ is the density of the kerosene (liquid) at the given temperature.

The values of K and K_1 at various t and t are calculated in advance. The change in the volume of the burette under the influence of the surrounding temperature is not taken into consideration.

The complete formula for applying the reading of V on the burette to the volume of the spaces under normal conditions is:

$$V_0 = (K - K_1)V$$

Usually, the volume V_0 pertains to unit weight or what amounts to the same thing that is to the unit volume of thaw water.

The Shuleykin instrument (Figure 67) consists of a glass beaker about 5 cm in diameter, containing a piece of ice some 100 g in weight and a glass hood with a burette equipped with a valve and a small reservoir having an opening. The junction point between beaker and hood is conical, ground in, and smeared with vaseline to prevent the entry of air. A spout is fused to the bottom of the beaker. Seated on the spout is a rubber tube to admit liquid (turpentine). A piece of ice of known weight placed in the turpentine thaws. The water accumulates at the bottom of the beaker, and the air from the spaces in the glass rises to the top of the burette where its volume is counted off downward from the cock.

The air-space content of the ice is calculated in the same manner as with the Arnol'd-Alyab'yev instrument.

3. The thermal expansion of ice is one of its most important properties and is of practical value as changes in the volume of ice due to fluctuations in the temperature of air above the ice cover are a cause of the great pressures exercised by ice on hydraulic engineering structures. It must be stated however, that very little study has been given to this property of sea ice and a method of determining the coefficient of thermal expansion of ice in the field has hardly been worked on at all. Below we describe a method of calculating the coefficient of thermal expansion of ice developed by the Swedish physicist Malmgren during the drift of the "Maud" in the East Siberian Sea from 1922 to 1924. He found the coefficient of thermal expansion as the ratio of increase in the specific volume of ice to the accompanying increase in ice temperature.

The Malmgren instrument (Figure 68) consists of a cylindrical iron vessel known volume (450-500 cc). One end of the vessel is open, but may be screwed tight by means of an air-tight cap. B. A. calibrated graduate tube C, the bottom of which is on the same level as the lower surface of the cap is pushed through the cap. The weight of the entire instrument M is determined to an accuracy of 0.01 g. The total internal volume of the vessel and the glass tube to any graduation is calculated by the known coefficients of thermal expansion for iron and glass.

To determine the coefficient of thermal expansion of ice, one prepares a specimen of ice the shape and dimensions of which are similar to those of the vessel. The weight of the ice specimen P is also measured to an accuracy of 0.01 g. All air bubbles are

removed from the walls of the ice specimen and from the inside walls of the vessel before the ice is placed within it. The immersion of the ice specimen in a vessel containing kerosene, and the removal of the air bubbles is performed in a kerosene bath at low temperature without access of air. As soon as the ice specimen has been placed in the vessel the cover is screwed down tight and the apparatus is removed from the kerosene and shaken vigorously until air bubbles from the vessel no longer enter the tube. The apparatus is then wiped dry and weighed, to an accuracy of 0.01 g. The known weights of the full vessel g g, of the empty vessel M g, and the ice specimen P g are used to calculate the weight of the kerosene F g remaining between the walls of the vessel and the ice specimen.

$$F = g - (P + M)$$

The specific volume W_t of the ice specimen at any temperature t is determined on the basis of the total volume V_t of the kerosene and the ice.

This is done as follows. The full vessel is immersed into a kerosene bath of t temperature where it is kept for 4 or 5 hours (so as to permit the ice specimen to acquire a given temperature). A reading of the position of the kerosene in the glass tube is then taken. The inside volume of the instrument (V_t) is expressed by the formula:

$$V_t = \frac{F}{\sigma_t} + gW_t$$

so that the density of the ice is

$$W_t = \frac{1}{g} \left(V_t - \frac{F}{\sigma_t} \right)$$

where σ_t is the specific gravity of the kerosene at t degrees, g is the weight of the ice and F the weight of the ice and kerosene in the instrument.

Given a series of values of W_t (the specific volume of the ice) at various temperatures, the coefficient of thermal expansion of the ice U_t , is obtained from the formula:

$$U_t = \frac{\Delta W_t}{\Delta t}$$

in which ΔW and Δt are the respective increases in the specific volume and temperature of the ice.

4. Ice temperature is of particular interest both for the scientific and practical reasons. Problems of heat exchange between ice and the surrounding water and air, and the principles of the process of thaw, the strength of the ice cover, and a whole number of general and special problems in the study of ice are incapable of solution without knowledge of its thermodynamics. Unfortunately, systematic studies of the temperature of ice in natural conditions are not made even today, although the field methods of measuring ice temperature are now entirely reliable. These methods include the measurement of ice temperature by means of resistance thermometers and thermocouples.

Measurement of temperature by electric thermometers (resistance thermometers) consists of determining the changes in the electrical resistance of a fine (0.05-0.10 mm) nickel or copper wire, depending upon the temperature of the surrounding medium.

The apparatus for measuring temperature by electrical thermometers consists of the following major component (Figure 69): resistance thermometers (a), measuring instruments and leads to them (d, e, f, k, m, n), a current source (l), and a standard commutator.

Resistance thermometers consist of fine nickel coils in a brass cylinder, a cartridge protecting this element from mechanical

damage, and a 3 strand cable with gutta-percha insulation. The measuring instruments consist of a sensitive galvanometer f , and a resistance bridge m , mounted in a single box. A 2 or 3 volt battery serves as source of current l . The wires connecting the thermometer coil with the measuring component are also capable of undergoing changes in resistance. Therefore in order to deal only with changes in the temperature of the coil itself the third strand of the cable is attached to the end of the coil. This is then connected to the branch of a standard-resistance bridge. The thermometers are graduated for the entire possible range of temperatures to be measured.

The thermometers are frozen into the ice as follows. A small hole is chipped in the ice. A board 25 to 30 cm wide and long enough to permit observations when the ice attains the greatest thickness that may be expected, is frozen into the hole. Thermometers are mounted to the board at specified levels. As the ice cover thickens each thermometer successively freezes into the ice. The lead wires are laid over snow atop the ice, and are buried in more snow. A table, the base of which is frozen into the ice is set up nearby to carry the other instruments and batteries (Figure 70). Before the readings all the leads from the thermometers are connected to the measuring instruments. Readings on the dial of the resistance bridge are taken for each thermometer in order. By moving the sliding resistance contact along the rheochord m , a point is reached at which there is no current in the galvanometer. This is checked by pressing the current switch button. At this point the reading is taken. The rheostat reading is converted to degrees centigrade by means of a calibration curve or table.

Thermoelectric measurement of ice temperature is based on

the development of current in the circuit between 2 couples of different metals at different temperatures (Figure 71). One is in contact with the medium whose temperature is being determined and the other of known temperature is connected to a sensitive galvanometer. The following metals of which the corresponding couples are made are the best suited for this purpose: constantin and copper, constantin and iron, and constantin and silver. The thermoelectric current of these couples is related to ice temperature by the following formula:

$$D = a \left(\frac{t}{100}\right) + b \left(\frac{t}{100}\right)^2 + c \left(\frac{t}{100}\right)^3$$

in which D is the thermoelectric current, t is the temperature of the ice and a, b and c are constant coefficients for the given couple as indicated in the table below.

TABLE 24

Constant coefficients				
Thermocouples	a	b	c	Interval
Constantin-copper	3.60	0.444	-0.023	-185 to 500°
Constantin-silver	3.38	0.348	-0.055	-0.055 to 600°
Constantin-iron	4.65	0.374	-0.049	-185 to 600°

Calculation on the basis of measurements of thermoelectric force are based on the formula:

$$t = 100 (\alpha D + \beta D^2 + \gamma D^3)$$

The values of α , β , γ for the different thermometers are as follows:

TABLE 25

Thermocouples	α	β	δ
Constantin-copper	0.308	0.0144	-0.00026
Constantin-silver	0.252	-0.00334	-0.00004
Constantin-iron	0.227	-0.0045	-0.0001

The thermocouples are of fine-gauge, well-insulated wire, 0.3 mm in diameter, and are fastened to a wooden board which is frozen into the ice. Copper contacts are soldered to the galvanometer leads. The contacts are marked plus and minus, the signs being determined during calibration, which is performed as follows. A mixture of water and snow, into which one of the ends of the thermocouple is immersed is made in a glass beaker which may be either a thermos container or a cylindrical Dewar flask. The other end of the couple is placed in a spacious vessel containing alcohol under constant agitation which is brought to various temperatures. The thermocouple terminals are connected to a galvanometer. The temperatures of the alcohol and the thawing snow are measured by an ordinary mercury thermometer. At the same time, a galvanometer reading is taken, and the value of a graduation is determined. The temperature coefficient, i.e., the percentage change in galvanometer reading per degree of change in air temperature, has to be known for each galvanometer. The observations themselves are taken in a manner analogous to the calibration procedure, except that one end of the thermocouple is immersed in the ice, the temperature of which is being determined. A series of thermocouples connected in series constitute a thermo-battery, (Figure 72). Its use increases the accuracy of the findings.

Mechanical Properties of Sea Ice

The capacity of ice to resist various external forces constitute its mechanical properties just as with any other solid.

Study of the mechanical properties of ice in general and of sea ice in particular is a very young branch of ice research, and began in the thirties of the present century.

Very intensive study of the mechanical properties of ice, particularly salt ice, was conducted just prior to and during World War II, primarily in conjunction with problems of ice crossings and the increase in the operations of the icebreaker fleet. However due to the extreme lack of uniformity of ice cover as to structure and composition and the widely differing conditions of its development and existence knowledge of the mechanical properties of sea ice is very incomplete, despite pressing practical needs.

Basic Concepts of the Mechanical Properties of Sea Ice

Sea ice, like the vast majority of solids, has elastic and plastic properties meaning that external forces may cause it to enter elastic or plastic states, and that it is brittle only under specific conditions.

The state of elasticity is characterized by the fact that the deformation of a body does not change during the entire period during which a constant stress is brought to bear and is zero after this stress ceases, so that the body returns to its initial form and volume.

In the state of plasticity, a constant stress results in constant increase in deformation, the residual deformation being close to that existing at the moment when the force ceases to act. It may be brought to zero by an opposite stress operating during an identical period of time.

The state of brittleness is characterized by the fact that,

under a constant stress, the body breaks into pieces gradually or suddenly, and is therefore incapable of being returned to its initial form and volume by an opposite force.

The elastic limit of salt or fresh ice, i.e., the stress at which ice loses its elasticity and becomes plastic, is very low, apparently not exceeding 0.6 to 0.8 kg per square cm. For the ice of the Neva River the figure is 0.57 kg/cm². Determination of the elastic limit of ice is not only of theoretical but of practical interest (for analysis of crossings on ice, measurements of the thickness of glaciers and icecaps by echo sounding, etc). However it is exceedingly difficult to find the true value of this limit under natural conditions i.e., when ice overlays water. To this day only a very small number of even relatively reliable data obtained by determination of the rate of propagation of vibration in bars of ice (thus not under natural conditions) are available. Determination of the elastic limit of ice is usually made by means of the so-called elastic constants: the modulus of elasticity (Young's modulus), Poisson's ratio, and the shear modulus.

The modulus of elasticity is the reciprocal of the coefficient of linear elongation of a body due to the tensile effect of stress, i.e.,

$$E = \frac{1}{\alpha} = \frac{L}{\Delta L} P \text{ kg/cm}^2$$

where E is the modulus of elasticity, α is the coefficient of linear elongation (or diminution), L is the length of the body (i.e., of a bar of ice), ΔL is the elongation of the body under load, and P is the weight of the tensile load per unit area of cross-section of the body.

Poisson's ratio (σ') is the ratio of the coefficient of transverse

constriction or dilation to the coefficient of linear elongation (α).

$$\sigma = \frac{\beta}{\alpha} = \beta E = \frac{\Delta d}{d} : \frac{\Delta L}{L}$$

in which d is cross-sectional area.

The shear modulus (N) is the force required to revolve a normal to an angle taken as unit (57.3°). It is calculated by the formula

$$N = \frac{1}{n}$$

If 2 parallel planes in a solid affected by some force are shifted with regard to each other so that the initial normal to these planes is caused to deviate by a given angle, then $w = np$, in which w is the angle of inclination from the normal, p is the force at work, and n is the shear coefficient (a constant for the given body).

The relation between the shear modulus, modulus of elasticity and Poisson's ratio is expressed by the formula $E = (2N - 1)\sigma$.

Determination of the elastic constants of ice like determination of elastic limit involves considerable technical difficulties and is therefore not performed under field conditions.

Systematic studies of variability in the modulus of elasticity and Poisson's ratio for ice have been made by V. M. Pinsgin, who found the following:

- (1) the modulus of elasticity shows a marked decline with constant increase in stress;
- (2) the modulus of elasticity is greater in deformation transverse to the crystals than in longitudinal deformations;
- (3) the modulus of elasticity increases with decline in temperature;

(4) the modulus of elasticity in the upper layers of ice is greater than in the lower; and

(5) Poisson's ratio increases with rise in load, and with decline in temperature.

The stress at which a body loses plasticity and begins to become brittle is usually termed the critical point, or (by analogy to the elastic limit) the plastic limit. The state of the ice in the plastic state is doubtless of high scientific interest, but for practical workers it is important to know not the changes in deformation while stresses are at work, but primarily the magnitude of the plastic limit (the critical point, breaking stress, or strength).

If the use of ice as a building material is under study (for ice crossings, various structures, etc), the minimal loads at which the given ice will undergo destruction are the items of major interest.

However, if the problem is that of combatting ice (in icebreaker work and stressanalysis of hydraulic engineering structures), the prime factors for researcher and engineers are the stresses which ice can withstand before breaking into pieces.

Reference to the mechanical properties of ice usually pertains to determination of its plastic limit (strength). As, in nature, outside forces affect the ice cover in a variety of ways, the force (load) brought to bear on ice in laboratory and field tests of plasticity is applied in a variety of ways.

Most common are tests for compression, flexure, and tension. Less attention is paid to determination of the plastic limit of

ice on instantaneous compression (shock) and shear. However, these tests are also quite important in determination of the mechanical properties of ice, and should be made systematically.

The mechanical properties of ice are tested on samples in the form of rectangular parallelepipeds or cubes, with carefully polished and accurately measured edges as it is necessary to know the cross-section of the ice specimen in the final calculation of the plastic limit. These specimens are prepared as follows. First a large block of ice is cut out. This is then sawn into bars, the dimensions of which must be 1 to 2 cm greater than the final specimen, to provide a margin for polishing. Finally each bar is given accurate shape and polish either by an ordinary carpenter's plane or a special polishing lathe.

Cubes from 5 X 5 X 5 to 10 X 10 X 10 cm are used in tests of compressive strength.

Rectangular parallelepipeds measuring from 5 X 5 X 30 to 10 X 10 X 50 cm are used to test flexure (fracture), tensile and shock strength.

Prior to the test the ice is seasoned for an extended period in a room the air temperature of which is the same as that at which the test will be run. This is then taken to be the temperature of the ice at experiment. To prevent that temperature from changing, all tests must be run quite rapidly.

In flexure tests, for which ice "keys" consisting of blocks of various sizes, are used, the temperature of the ice is taken to be either the air temperature at the moment of test, or the temperature of the ice from which the "key" has been cut.

As the plastic limit of the ice depends not only on its

temperature, but also on structure, porosity and salinity, these parameters also have to be determined. In addition, it must be remembered that the mechanical indices of the various layers of the ice cover are not identical. They also vary with the direction of the application of stress relative to the axes of the crystals. The tests are therefore run on specimens from various levels of the ice cover and with their crystalline axes running in various directions relative to that from which the outside force is applied.

Finally, the mechanical properties of ice are dependent to a considerable degree on the length of time during which the load is applied, a fact that must be taken into consideration in tests.

1. Tests of ice for compressive strength are run either in one of a number of types of presses or on special machines. Below we offer a brief description of the Whitman-Shandrikov press (Figures 73 and 74).

The worm gear 1, and wheel 2, actuated either by hand or electric motor the inferior jaw 4, serving as base, and carrying the ice specimen 7, is raised on the threaded shaft 3. The resistance of the specimen P, is transmitted to the upper jaw 8, via a ball 9, at the bottom of a rod 10, which moving in the guides 11, actuates with its other end, the second-class lever 12, with a force equal to the resistance of the specimen. By means of the hanger, 13, the left arm of lever 12, transmits this stress, reduce by the ratio $\frac{a}{B + a}$ to the spring 14. The pressure transmitted is determined by the degree of deformation of the spring. The deformation of the spring is evaluated (to an accuracy of 0.01 cm) by means of the dial 15, which is mounted on the frame of the press.

The formula for calculating the plastic limit of ice in tests for compressive strength looks as follows $R = \frac{p}{lb}$ kg per square cm, in which R is the plastic limit (the critical strength) of the ice p is the force applied in kg, l is the length of the specimen, and b the specimen's width.

2. Tests of ice for flexure are run on hydraulic presses specially designed for the purpose, and also on Whitman-Shandrikov and other presses.

The simplest is the Arnol'd-Alyab'yev press (Figure 75) consisting of 2 extension frames from which a bar of ice is suspended on rubber gaskets. The load is applied upward by means of a swivel arrangement. The bar to be flexed to breaking is in the plane of the upper beams of the frame. The supports and the working edge in contact with the ice are of hardwood, and are cylindrical, with ample curvature. Pressure is applied by turning the swivel by hand, so that some unevenness in the rise in stress is unavoidable. The pressure on the ice is measured by a dynamometer with an oval steel spring. To avoid the possibility of spoiling the dynamometer mechanism by rapid release of load when the ice bar breaks, a special safety device is provided.

The formula for determining the plastic limit of ice (in kg per square cm) to flexure on the Arnol'd-Alyab'yev press is as follows:

$$R = \frac{3}{2} p \frac{L}{h^2 b}$$

in which R is the plastic limit in kg per cm², p is the stress applied, in kg, L is the span of the frame, h is the height of the specimen in cm, and b is its width in cm.

Determination of the flexing strength of ice is also performed by means of ice "keys" sawn from the ice cover.

Such determinations enjoy a great advantage over tests of small ice specimens, as they make it possible to obtain data on the strength of the natural ice cover.

There are several types of frames for testing ice "keys" for flexure or fracture of which the most successful must be deemed that designed by I. P. Troshchinskiy. The advantage of this frame over others lies in the fact that the ice "key" retains its connection to the ice cover.

The Troshchinskiy frame (Figures 76 and 77) consists of a wooden lever to one end of which there is attached an iron hook carrying a chain which is placed beneath the "key," while to the other there is connected an iron bracket through which a screw with a swinging handle-bar is connected. A dynamometer is attached to the lower end of this screw and is firmly seated in the ice cover. During the test of the "key," the wooden lever of the device rests on a support beam, the distance from the middle of the beam to the point at which the iron hook is fastened to the chain, on the one hand, and to the screw with the dynamometer on the other, being measured accurately. This appliance makes it possible to make tests for flexure (fracture) with stresses applied both downward and upward. When the stress is applied downward, the apparatus is a second-class lever, and when upward a first-class lever (Figures 76 and 77).

The magnitude of a stress directed downward is calculated on the formula

$$F = \frac{PL}{2L} + (f + f_1) \frac{L}{L} + p$$

while one directed upward is measured on the formula

$$F = \frac{P(L - l)^2}{2Ll} + \frac{(f + f_1)(L - l)}{L} - \frac{p}{2L}$$

in which P is the weight of the lever, p is that of the support beam, f that of the hook and chain, f_1 is the total weight of dynamometer, screw, handle, and other parts on the long end of the lever, L is the total length of the lever and l is the short arm of the lever.

The plastic limit on flexure is obtained on the formula

$$\sigma = \frac{6 Fa}{bh^2}$$

in which σ is the critical point in kg per square cm, F is the stress in kg, a is the length of the "key" from the point of application of the stress to the fracture line, in cm, b is the width of the "key" in cm, and h is the height of the "key" (the thickness of the ice cover) in cm.

3. Tensile strength tests of ice make it possible to determine the elastic limit at fracture. In the simplest arrangement, the device for testing the ice consists of 2 clamps gripping the ends of the specimen. The upper clamp is attached to a fixed beam and the lower to a pan for the load. A test consists of adding weights to the pan until the specimen yields. The plastic limit is calculated on the formula

$$R = \frac{P}{bh} \text{ kg per cm}^2$$

in which R is the plastic limit, p is the force applied in kg, b is the width of the specimen in cm and h is its height in cm.

4. Tests of ice for shock may be performed on the V. S. Nazarov swing impact machine (Figure 78). The basis of the machine is pendulum carrying a load at the end. The pendulum is attached near its top by a mount having an angle gage to determine the angle of swing after the specimen has been destroyed. Near the

top of the mount which is fastened to a horizontal base, there is a stop to hold the pendulum at the desired initial position. Ice specimens measuring from 5 X 5 X 30 to 10 X 10 X 30 cm are used. The specimen rests on supports 10 cm apart. When everything is in place the catch is removed and the pendulum strikes the specimen. Destruction is by the blade of the pendulum, the contact portion of which is a semi-circle of 5 mm radius.

The work performed by the falling pendulum is calculated on the formula

$$T_0 = p\left(\frac{1}{2} + \frac{1}{2} \cos \alpha\right) + p_1 l_1 (1 + \cos \alpha) + p_2 l_2 (1 + \cos \alpha)$$

in which T_0 is the total work performed, p is the weight of the pendulum, l is its length, p_1 is the first weight added, p_2 the second, l_1 the distance from the axis of rotation of the pendulum to the center of the first weight (p_1), l_2 the distance from the pendulum's axis of rotation to the center of the second weight (p_2), and α is the angle to which the pendulum is raised in its initial position. After destroying the specimen the pendulum continues to swing and the height to which it rises indicates the unexpended portion of its force.

The force expended in destroying the specimen by impact is calculated on the following formula:

$$T_d = g(h - h_1)$$

in which T_d is the work required to fracture the specimen, g is the weight of the pendulum (β) with its weights, $h = r(1 + \cos \alpha)$ is the height of the center of gravity of the pendulum before the blow, and h_1 is the height of the center of gravity of the pendulum after the blow.

With allowance for losses, the final formula is as follows:

$$T_d = T_a - \Delta T_a - T_\beta + \Delta T_\beta$$

in which ΔT_{α} is the loss in the initial force, T_{α} by friction in the ball-bearings and overcoming the resistance of the air, ΔT_{β} is the loss in live force, T_{β} , as the pendulum swings by angle β after destroying the specimen.

It is necessary for the angle of elevation of the pendulum in its initial position α , to be constant, as the constancy of the force T_{α} is dependent upon this.

For convenience of calculation a table is used providing the values of T_{β} kg relative to the angle β .

5. Shear tests (Figure 79) are performed by a method developed by I. P. Troshchinsky.

An ice drill and a special reamer are used to bore an incomplete hole in the natural ice cover with a constriction at a given depth (Figure 80). The diameter of the hole is 3 cm, 2 cm at the constriction. The depth is determined by the bit. The test consists of shearing the ring of ice. The major component of the shearing instrument, a plunger (1), consists of a brass cylinder connected by a ball-shaped heel to the base 2, in the form of a cushion block. A steel tube 3, serves to transmit pressure on the dynamometer is transferred by means of a wooden lever 5, with metal handle by which the lever is seated on the tip of the dynamometer. A steel cable fastened to the ice by a dog 6, is fastened to one end of the lever. The ring is sheared through by even pressure on the handle of the lever. The moment of shear is determined by feel. The dynamometer shows the maximum force exerted.

The critical point of resistance to shear is determined by the formula

$$R = \frac{P}{dh}$$

in which R is the critical resistance in kg per cm^2 , P is the stress applied in kg, d is outside diameter of the ring in cm and h is the height of the ring in cm.

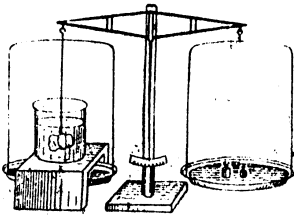


Figure 64. Apparatus for determining ice density by hydrostatic weighing.

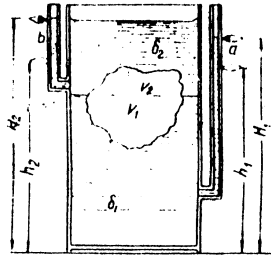


Figure 65. Shuleykin's apparatus for determining ice density

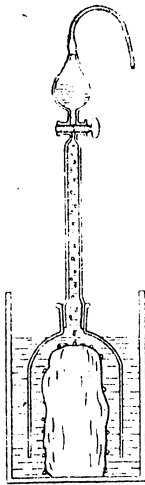


Figure 66. Arnol'd-Alyab'yev's instrument for determining ice porosity

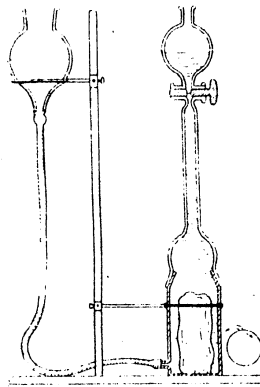


Figure 67. Shuleykin's apparatus for determining ice porosity

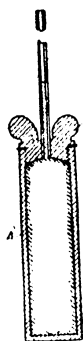


Figure 68. Apparatus for determining the coefficient of thermal expansion of ice

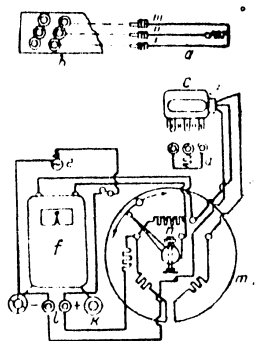


Figure 69. Method of connecting resistance thermometers. (a) thermometer, (b) commutator, (c) Y connection; (d) control; (e) bridge dial illumination; (f) galvanometer; (k) corrector; (l) battery; (m) rheochord; (n) push-button switch.

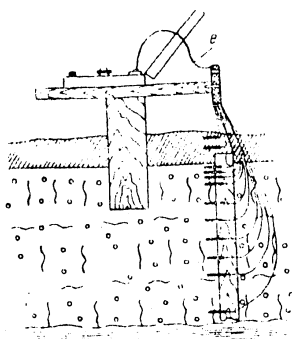


Figure 70. Method of inserting resistance thermometers in ice

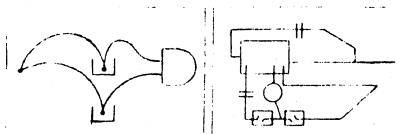


Figure 71. Method of setting thermocouples

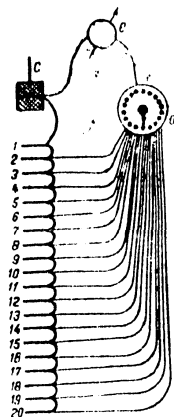


Figure 72. A battery of thermocouples

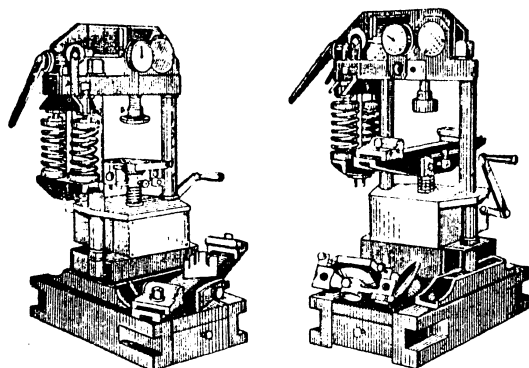


Figure 73. Whitman-Shandrikov press, general view

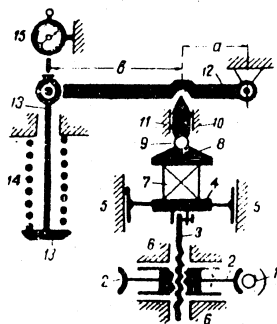


Figure 74. Design of Whitman-Shandrikov press

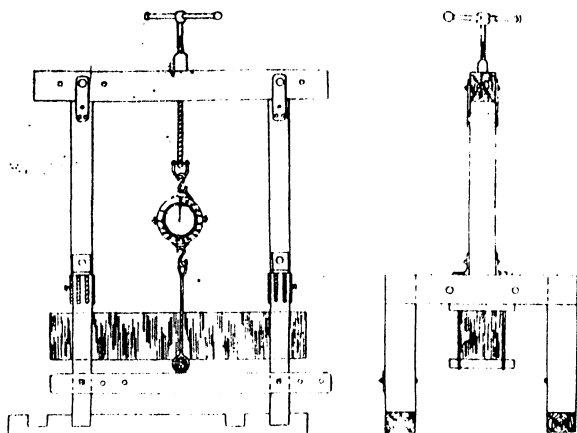


Figure 75. Design of Arnol'd-Alyab'yev press for testing ice for flexure

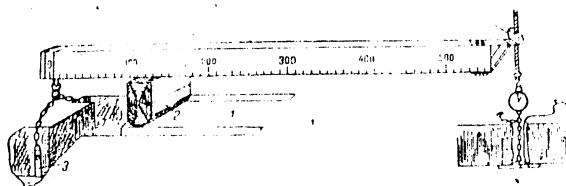


Figure 76. Design of Troshchinskiy apparatus for testing "keys" of ice for flexure (stress directed downward). (1) "Keys," (2) bearing beam; (2) support beam

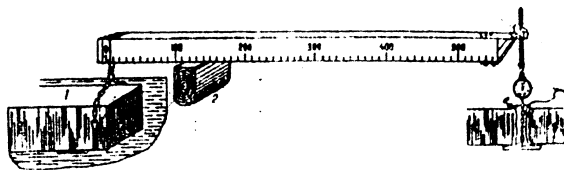


Figure 77. Troshchinsky's apparatus for testing "keys" of ice for flexure (stress directed upward). (1) "Key", (2) support

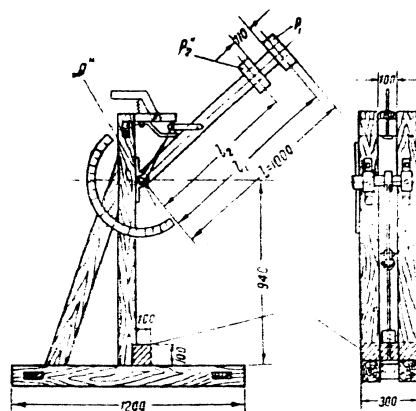


Figure 78. Nazarov's pendulum impact machine for testing resistance of ice to shock

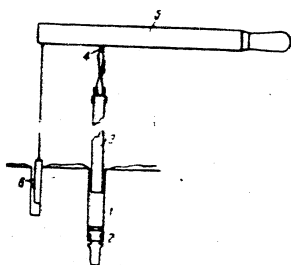


Figure 79. General design of Troshchinsky's apparatus for testing shear strength of ice

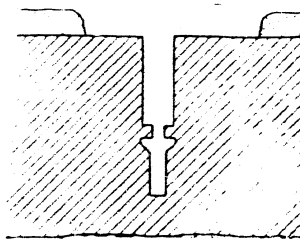


Figure 80. Schematic of hole for testing shear strength of ice by Troshchinsky's method